SIMULATION MODELING AND ANALYSIS OF F-16 PILOT TRAINING SQUADRON

THESIS

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## Abstract

The need for fighter pilots in the Turkish Air Force is expected to increase with the planned acquisition of Joint Strike Fighters, ongoing new F-16 purchases, and other upgrades to the Turkish Air Force fighter inventory. This increased demand will affect the current fighter training squadron curriculum and scheduling. This study focuses on issues related to $143^{rd}$ Oncel squadron F-16 Pilot Training with this projected increase in number of student pilots (SP). Completing the training periods on time is an important issue along with maintaining effective training performance. In our study the Total Time of the training period serves as our primary performance measure. Simulation modeling concepts are applied to examine the training period based on the squadron syllabus. After constructing a simulation model using Arena, Design of experiment, Regression Analysis and Metamodeling are implemented to capture the effects of the major factors, including SP, Instructor Pilot, Bandit and F-16, and how they interact with each other. The utilization of IP and Bandits is also examined as a performance measure. In addition we conduct a sensitivity analysis using our model with the current $143^{rd}$ Oncel squadron resources.

## Acknowledgments

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Adem Okal

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# SIMULATION MODELING AND ANALYSIS OF F-16 PILOT TRAINING SQUADRON

## I. Introduction

### 1. Background

Turkey has a significant military superiority over the Southeastern region as a NATO member. Certainly airpower is the leading factor to maintain this current military presence. When one visualizes airpower, the first thing that comes to mind is flight. Beside new generation aircraft, the human factor arises as a key factor which has a direct relation with airpower sustainability. An Air Force with many kinds of modern aircraft without well-trained pilots would not have the ideal effectiveness. Beside ground support, it is obvious that aerial performance depends on how successful pilots handle their assigned missions as well as what type of modern aircraft they fly. Performance can be monitored and improved by assessing the quality of the flight courses and how successfully pilots complete these courses.

In Turkey, there are several flight training schools for basic, intermediate and professional phases. The only squadron is the 143rd squadron, also called Oncel squadron stationed at 4th Main Jet Base, Akinci. It is the only squadron where all F-16 fighter pilots

are trained through the B course which undergraduate pilots take to become F-16 pilots. In addition, the squadron administers a refresher course for pilots who have been away from active duty for a certain time. The goal of the B course, which is the main focus of this thesis, is to train F-16 pilots with basic proficiency in F-16 air-to-air and air-to-surface mission tasks. The graduate pilot is considered to have fulfilled all requirements as a combat ready pilot except for orientation training at his or her assigned squadron.

The B course is the main focus of Oncel's mission. The B course is a 62-sortie flight training program that consists of three different flying phases shown in Table 1. The first phase of the B course is called Basic Training, which is comprised of two sub phases, basic training (BTR) and basic instrument (BIF). The Air-to-Air (AA) phase is the second phase of the B course and consists of basic fighter maneuver (BFM), air combat maneuvering (ACM) and basic intercept (BI) sub phases. The third and final phase of the B course is the Air-to-Ground (AG) phase. The AG phase is comprised of six sub phases. At the end of the AG phase, the Instrument qualification (IQ) and Tactical qualification (TQ) check rides must be accomplished to be able to graduate successfully from the B course (143rd Training Syllabus, 2003).

Table 1: Sortie distribution of Oncel squadron

| | TRANSITION | AA | | | AG | | NIGHT | CHECKS | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | BTR | INTERCEPT | BFM | ACM | SA | SAT | NTR | TQ | IQ | TOTAL |
| SORTIE | 9 | 7 | 13 | 9 | 8 | 11 | 3 | 1 | 1 | 62 |

In addition to these flight phases, academic and device training are scheduled as a supporting part before or during the B course. The time constraint to finish this process successfully is 140 weekdays based on a class of 20 Student Pilots (SPs). Of the 140 weekdays, 35 are shared for academic, simulator and device training, and the remaining 105 for flight training.

In every training period approximately 20-25 student pilots attend B course. The daily number of sorties for the Oncel squadron is approximately 40, corresponding to 20 mission sorties, which shows that most missions are accomplished with more than one aircraft.

The pilots other than student pilots are classified as instructor pilots (IPs) and Bandits who fly as a support unit. The group for Bandits contains all the non-student pilots in the squadron. Bandits are required to fly certain assigned missions before becoming IP. Bandits fly support flight, which are required for multi-aircraft mission. Besides these support flights, Bandits also are required to fly a certain number of sorties according to regulations to maintain their currency for various missions.

### 1.2. Problem Statement

Turkey has a big role in the NATO environment as an air force power over the region. To maintain this effectiveness and to meet the increasing needs for air force power, Turkey is giving more importance to aviation. Over the next few years, the Turkish Air Force is planning to buy more F-16s to update their current inventory and replace lost aircraft. Turkey is also one of the contractor countries of the Joint Strike

Fighter (JSF) project, and plans to add this aircraft to their inventory by 2013. This new aircraft will require pilot transitions from F-16 and F-4 squadrons, while still maintaining the required number of pilots in all fighter squadrons. This increased demand for pilots will require a larger number of student pilots enrolled in each class for the 143rd Oncel squadron. To complete training within the same time frame with an increased number of student pilots, Oncel needs to come up with some predictions to meet these demands through additional IPs, Bandits and aircraft.

### 1.3. Scope

The scope of this thesis research is analyze the B course in detail to understand the effects of changing defined variables, including number of SPs, IPs, Bandits and aircraft. This analysis includes construction of a detailed computer simulation of the entire training phase using the Arena discrete event simulation software package. The model is used to explore major factors that affect the training process to include the time duration of the training, the number of SPs, IPs, Bandits and aircraft. This analysis provides insight to see how many additional weekdays, IPs or Bandits will be needed to have a certain number of SPs graduate from the Oncel squadron. With this study it is proposed to have an idea about which major factor or factors are affecting the duration of flight training period.

## 1.4. Thesis Organization

In this chapter the main concern is spent on providing a background about the F-16 pilot training process and its sub phases. Chapter 2 presents a literature review about the tools used to analyze this problem. Additionally, a discussion is provided on why simulation was chosen as a research tool. Chapter 3 give details about modeling the real system by using Arena. Chapter 4 presents the outcomes of the simulation and the analysis. Chapter 5 summarizes all the phases of this research, contributions, and also recommendations for further research.

# II. Literature review

## Introduction

This chapter first describes the training process in the Oncel squadron, and secondly covers the topics related to simulation building, advantages and disadvantages of simulation. Also Arena, a simulation software package, is briefly discussed in this chapter. Finally previous research is presented at the end of the literature review.

## 2.1. Description of Flight Training

The F-16 Pilot Training in Oncel squadron consists of three phases, BTR, AA, and AG. There are two training terms in each year. During these terms, a certain number of SPs attend the flight training course. From a modeling perspective, each flight training term can be thought of as a production line in a factory consisting of several stations or a multi-stage flow shop line. In the conceptual model, a SP acts as an entity in the system. Every SP enters into the training process, goes through all sub phases consecutively, and at the end of the training graduates by accomplishing all sorties as planned. In this flight training process, there are some primary constraints including the number of IPs, Bandits, aircraft, and daily sortie blocs. Beside these constraints, meteorological conditions, runway availability, aircraft maintenance can be assessed as secondary constraints.

Every graduation date is determined before the training term starts. If maintaining a high quality training program is the primary objective of Oncel squadron, then having all SPs graduate on time becomes a secondary objective. For most of the training terms, the numbers of the IPs, Bandits and aircraft usually show little fluctuation. On the other hand, the number of SPs may change significantly depending on the number of SPs graduating from the basic flight course. As a result, the number of SPs for each IP and Bandit increase as the number of SPs increases if the numbers of IPs and Bandits do not change during each training term. This fact means that IPs and Bandits fly more or less sorties depending on the number of SPs.

It is proposed that a model can be built to see how the system reacts if there occurs a significant increase in the number of SPs. The analysis of the interactions between system variables like numbers of IPs, Bandits, SPs and aircraft, and the effect on system performance (Total Time of SPs in training) is the main concern of this research. There are several approaches using common operations research tools to analyze this problem. These approaches include linear programming, integer programming, scheduling theory, and simulation. These approaches fall under mathematical models shown at Figure 1. Simulation modeling is chosen as the approach for this research.

For an analyst, completing a study in a faster and more efficient manner is generally preferred. Up front, the analyst must decide which solution technique to employ for the problem at hand. Definitely time is a key factor in determining an appropriate solution method as well as other resource constraints such as costs and computer hardware and software availability.

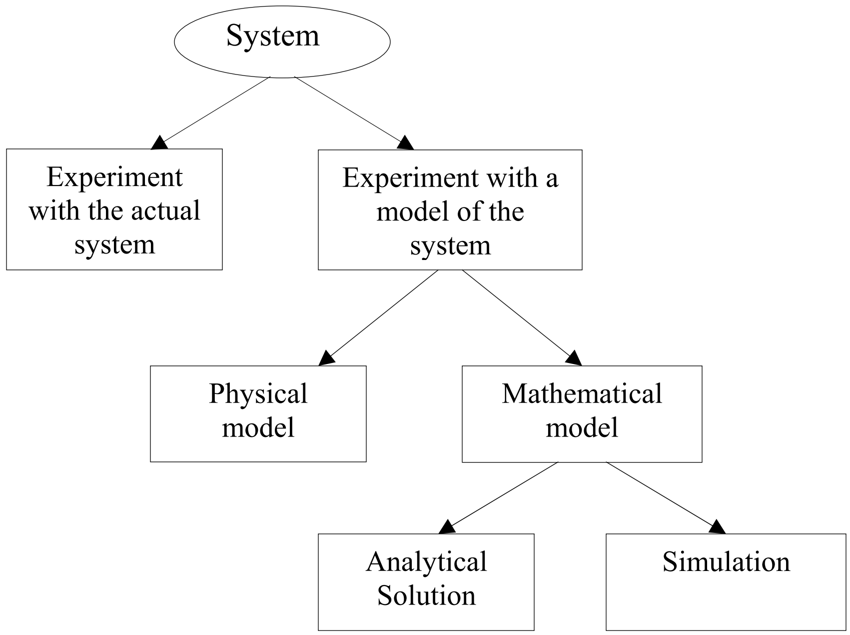



Figure1. Techniques to analyze a system (Law, 2007: 4)

What makes simulation preferable and more efficient over other methods is a question which has a subjective nature as well. The following section of this chapter discusses simulation in more detail.

## 2.2 Simulation

"Simulation refers to a broad combination of techniques and applications to imitate the real systems. Simulation is usually implemented on computer by using several available software tools. Furthermore, it can be said that simulation is a general expression since the idea finds its applications across many fields and industries" (Kelton, Sadowski and Sturrock, 2007:1). Simulation deals with systems and models of

systems. Simulation can be described as a depiction of real world systems in a computer generated environment, often times with a high quality visual representation.

To answer the question of what kinds of systems can be modeled, some examples from daily life follow:

- A freeway system of road intersections, controls, and traffic.
- A supermarket with inventory control, checkout, and customer service.
- An emergency facility in a hospital, including personnel, rooms, equipment, and patient transport.

In the area of military applications:

- A military depot handling maintenance supplies.
- A transportation processes between bases, deployment process.
- Airlift operations in a certain region.

### 2.2.1. Simulation Classifications

Simulations are traditionally grouped in three classifications as discussed below, although there are many various classifications for simulation in the literature. A static model is defined as a depiction of a system at a specific time. If time does not play a role in the system's nature, then the system can be modeled statically. On the other hand, if time plays a role in the system's processes, then it can be modeled dynamically. A dynamic model is a representation of a system as time changes. Monte Carlo models are good examples for static simulation modeling. Our F-16 pilot training squadron is a good example for dynamic simulation modeling.

A model is called deterministic if there are no random inputs to the system. In this category, a system's response is known for sure with a given set of deterministic inputs to the model. If a system is simple enough and does not have a stochastic nature, other techniques, like differential equations or linear programming, are more appropriate than simulation modeling. On the other hand, if a system has randomness in the nature of either its inputs or processes, then a system's model is called stochastic. A stochastic simulation model has at least one random input or process which results in random outputs. These random outputs produce results that approximate the true system performance and are one disadvantage of simulation models.

If the state variables of the system change continuously over time, then the model is described as a continuous simulation model. Density of airflow through an engine compressor, water levels of a dam, and traffic density on a highway are some examples of a continuous simulation model. On the other hand, for a discrete simulation model, the state variables of the system change only at discrete points in time. Inventory level of a military depot, emergency room patients in a hospital, and number of customers in line for checkout at a grocery are some examples of a discrete simulation model. It is possible to model a system containing both continuous and discrete features. Such models are called mixed continuous-discrete simulation models. "Practically few systems are totally discrete or continuous, however it is generally possible to define any system as either discrete or continuous since one of the classifications is superior to the other in most systems" (Law and Kelton, 2000:72).

### 2.2.2. Advantages and Disadvantages of Simulation

Simulation modeling is currently being used in many fields and becoming more common day by day. There are lots of ongoing practical application and theoretical research generating new aspects of simulation. Here in this section, some advantages which made simulation a prominent tool are listed below.

1. Simulation is relatively efficient in modeling complex systems. Most complex systems can not be analyzed via analytical approaches.
2. Simulation provides a tool for analyzing new policies and procedures without changing the real systems.
3. Simulation is an efficient tool to make an investigation for non-existing systems, vehicles, and so on. It provides a means for assessing all possible conditions and policies which may be significant factors in a system.
4. Comparisons between alternative models and policies can be done more effectively via simulation.
5. Simulation modeling provides not only numerical measures of system performance, but also provides insight into system performance.
6. Simulation with animation features aids verification and validation efforts.

In every circumstance, it is not logical to select simulation modeling as the analysis approach. Beside its advantages, there are some disadvantages which should be considered as well.

1. Simulation modeling and analysis generally are expensive and time consuming. Even with a significant level of effort, a simulation study may provide an insufficient analysis and meaningless results.
2. Simulation does not give an exact solution, it is just an approximation.
3. Simulation outputs are difficult to interpret. Due to multiple random inputs, it may be hard to distinguish what model factors affect specific outputs and how.
4. Simulation requires special training. There are many ways to build a model via simulation, and it depends on a modeler's perspective to come up with an efficient model (Banks, Carson, Nelson and Nicol, 2006).

### 2.3. Simulation Steps

Simulation has seven steps to conduct a successful study which is called a "seven-step approach" (Figure 2) (Law, 2003:66). The first step in building a simulation model is to state the problem precisely. The problem should be initially expressed and stated in detail. Every question about the system to be included should be clear before going through the next step of the simulation modeling. Even with a good starting problem formulation, further discussions with the decision maker and Subject Matter Experts (SME) about the system should be ongoing to get more information to model the system as accurately as possible. A Type III error, solving the wrong problem, can be eliminated by understanding the problem and the decision maker's point of view clearly.

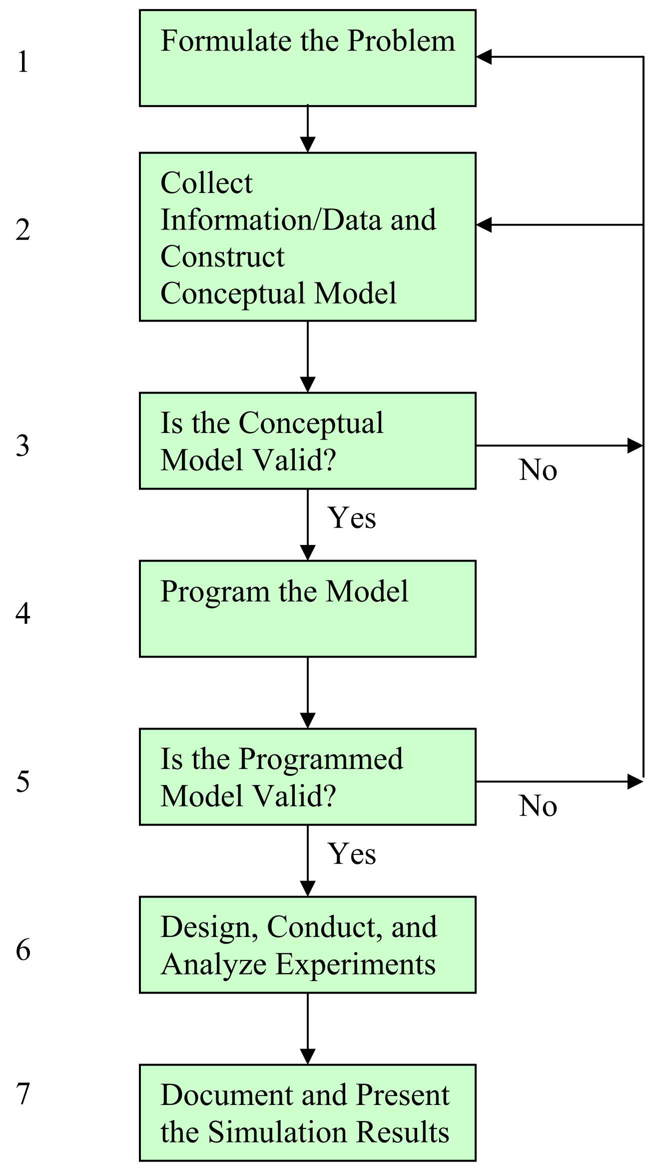



Figure 2: A Seven-Step Approach for Conducting a Successful Simulation Study (Law, 2003:67)

Data collection is needed to estimate the model input data. More accurate and precise inputs contribute to a more valid model, better suited to address the identified

problem. In general, it is difficult to find the required data due to several reasons as listed below:

1. Data not available
2. Data censored
3. Not enough data
4. Wrong data
5. Cost

For the case of having data in hand, the task is then to fit the data for a particular process through the use of a theoretical or empirical distribution. Many software packages have emerged for analyzing raw data and identifying appropriate probability distributions to use in a simulation model. Some of these tools are Bestfit, Input Analysis of Arena, Expertfit, etc.

After stating the problem correctly and collecting requisite data, it is time to construct a model using a commercial simulation package like Arena, Promodel, GPSS, or using general purpose computer languages like Visual Basic or JAVA. Choosing the appropriate modeling software depends on many factors including the analyst's preference, cost, availability of the program, and time available to conduct the study.

The purpose of model verification is to ensure that the model is constructed (coded) correctly. In other words, model verification assesses how well the model meets its specifications and implements what it is expected to do. In most cases, animation can be used as a tool to aid in verification.

There are various techniques which can be used to verify the model. While building a large and complex model, it is suggested that another person review the model for verification. This technique is called a structured walk-through of the program. Another technique involves running the simulation with different input data and checking the outputs to see whether they are reasonable. Most simulation software packages have some debugging capabilities. One common feature is called a trace. A trace provides detailed output for state variable changes and other user selected variables in the model.

"Validation is the process of reaching an acceptable level of confidence that the inferences drawn from a simulation are correct and applicable to the real-world system being represented" (Shannon, 1998: 11). Validation gives an insight to confirm that a model is a reasonable representation of the real system. It is not a one-time check, but an iterative process to ensure the accuracy of the model throughout a simulation study.

The first step from Figure 2 where validation is specifically mentioned is for conceptual model validation. In a conceptual model, the basic logic, structure, and interactions are depicted to understand whether the problem is captured correctly. Conceptual model validity considers whether (1) the theories and assumptions underlying the conceptual model are correct and if (2) the model's representation of the problem entities, the model's structure, logic, and mathematical and causal relationships are reasonable for the intended purpose of the model (Sargent, 2005:132).

> Operational validation is determining whether the simulation model's output behavior has the accuracy required for the model's intended purpose over the domain of the model's intended applicability. This is where much of the validation testing and evaluation takes place.

> Since the complete simulation model is used in operational validation, any deficiencies found may be caused by errors introduced in any of the steps that are involved in developing the simulation model (Sargent, 2005:136).

For operational validation, outputs from a model and a real system are compared by using graphical techniques to make a subjective decision, or through formal statistical techniques such as hypothesis tests or confidence interval to make an objective decision. Table 1 shows some techniques for each approach.

Table 2: Operational Validity Classification (Sargent, 2005:136)

| | Observable System | Non-observable System |
|---|---|---|
| Subjective Approach | • Comparison Using Graphical Displays<br>• Explore Model Behavior | • Explore Model Behavior<br>• Comparison to Other Models |
| Objective Approach | • Comparison Using Statistical Tests and Procedures | • Comparison to Other Models Using Statistical Tests |

Various validation techniques are discussed next. One of the techniques or any combination can be used for validation purposes. The choice of any techniques depends on the model developer. Generally some combination of techniques is preferable. Selection of techniques may be limited by time, cost, and other resources.

*Historical Data Validation:* After building the model, the model's validation can be done by using historical data if available. Historical data also can be used as input data

into the model. By running the system with given input data, the model outputs can be compared with the historical system output to see if the model acts as the real system acts.

*Comparison to Other Models:* The results from the current model are compared with other model's results which had been assessed as valid before.

*Extreme Condition Test*: This technique checks the model's reaction under extreme conditions. These extreme conditions include input data like assigning arrivals or inventory level as zero. As a rule of thumb, the output should be reasonable corresponding to the extreme input data.

*Face Validity:* Having the model checked by another person, as mentioned in verification section above in this chapter, is another technique for validation. This person should be a user of the system or someone with knowledge of how the system operates.

*Turing Tests*: The outputs from a real system and a model are collected as validation tools. Outputs from both sources are mixed and given to a SME or a well-knowledgeable user. If the SME or user discriminates between model and real system outputs, it shows that the model is not valid.

*Designing and Conducting Simulation Experiments:*

Before conducting simulation experiments, the analyst must decide a number of issues:

1. The input parameters to be varied, their range and legitimate combinations,

2. Model run length (how long to run the simulation)

3. Number of replications (Carson, 2003:21-22)

> All these issues depend on various factors like the amount of data at hand, the deadline for modeling, and the resources. There is no rule of thumb for run length or number of replications, each is model dependent. The number of replications affects statistical accuracy of performance measures; specifically, it affects the width of any confidence interval estimators (Carson, 2003: 22).

Design of Experiment (DOE) itself plays a unique role in designing and conducting a simulation experiment. DOE is the art of building a product or process by having all the factors under control. It reduces time to design and develop new products and processes, improves performance of an existing system, and achieves product and process robustness. In the context of a simulation experiment, it helps us obtain more and better information about system performance using less resources. For most simulation studies, it is impossible to analyze all possible combinations of factors involved with the model and how they affect measures of system performance and effectiveness. At this point, DOE is used as a solution technique to decide which factor combinations or design points to include in the experiment. Many software packages include DOE tools such as the Process Analyzer embedded in Arena, Design-Expert™ PQ systems™ and JMP.

*Document and Present the Simulation Results:*

> The basic aim of simulation modeling is to give accurate insight to a decision maker about a real system, not to make a decision. In general modelers spend most of their time on understanding a problem, building a conceptual model, implementing verification and validation and obtaining outputs from a model, leaving little time to work on packaging the results. If the results are not clearly, concisely and convincingly presented, they will not be used. The presentation of the results of the study is a critical and important part of the study and

must be as carefully planned as any other part of the project (Sadowski, 1993: 65-68).

### 2.4. Arena

There are many simulation software packages available if a modeler prefers not to write his own computer codes. This preference may be originated due to limited time. Arena is one of the simulation modeling tools which is flexible and powerful to represent real systems. It was released by Systems Modeling Corporation in 1993. It has been used as a simulation modeling tool in manufacturing areas, health care systems, call centers, warehousing, transportation systems, and so on.

"Simulation analysts place graphical objects – called modules – on a layout in order to define system components such as machines, operators, and material handling devices. Arena is built on the SIMAN simulation language. After creating a simulation model graphically, Arena automatically generates the underlying SIMAN model used to perform simulation runs" (Markovitch and Profozich, 1996: 437). Arena consists of several templates which can be defined as collections of more than one module.

Beside these templates, Arena has useful animations and graphical tools. These features visually provide clear understanding about processes in the model. Model verification and validation can be aided through the use of these features.

Arena itself is an effective tool which combines a number of analysis tools in one package. There are three additional tools in Arena, including the Input Analyzer, the Output analyzer and the Process analyzer. The Input Analyzer is an effective tool to analyze raw input data and determine a best fit distribution for incorporation in an Arena

model. The Output Analyzer is used after running a simulation model and includes various ways to display output data graphically. The Output Analyzer also provides confidence intervals, one-way analysis of variance and comparisons of alternative systems. Lastly, the Process Analyzer is used as an experimental design tool to see the system's response to different controls defined by the analyst. These controls can be possible number of cashiers, servicemen in a gas station, repairing stations, and so on. By using the Process Analyzer, the affects of different system policies can be evaluated without modifying the original model.

### 2.5. Previous research

Previous related research analyzing the Oncel training squadron as well as simulation studies of similar systems is discussed in this section. Cpt. Davut Aslan's (2003) research focused on the scheduling problem of the Oncel squadron daily sortie program. In his thesis, the time consuming scheduling problem of planning the daily and weekly flight program is thoroughly examined. His problem definition included certain basic resource constraints including number of instructors, bandits and aircraft. In addition his efforts showed that the effects of runway availability, non-flight duties and personnel activities can not be ignored. Aslan (2003) used integer programming and scheduling techniques to approach the problem. The objective function and constraints were formulated by considering all those factors stated above. His thesis also emphasized that the prediction of the end of the training term is possible by modifying the time

parameters in his integer formulations from weekly to new time parameters including the whole training program (Aslan, 2003).

For another effort, Maj. June Rodriguez (2007) was tasked to assess whether the USAF current cargo aircraft flying training resource capacity can accommodate additional student pilot demand due to an increase in C-17s and the newly implemented C-17 Abeam tactical requirement. She approached the problem by constructing a simulation to analyze the flight training term using Arena. Her simulation models aircraft scheduling of various combinations of C-5s, KC-135s and C-17s from FY07 to FY11. “Current syllabi for all three platforms, with consideration to future training starting in FY07, were used to model sortie profiles. The model's findings include the results of 1,000 runs for each FY. Multiple replications reduce the impact of modeling anomalies and show the overall limits on the resources” (Rodriguez, 2007).

Maj. Rodriguez’s model computes the total time in training days (noted in the model as time in system (TiS) each pilot needed to complete the flying training portion of his or her curriculum. The model output also includes the number of pilot types graduating from each course. “The Graduate Program Requirements Document (GPRD) is compared to the pilot graduates from the model while the model TiS is compared to the class type allotted flying training days” (Rodriguez, 2007).

> The simulation is verified by tracking individual entities through several key points in the system. The animation option in ARENA facilitates the verification process by allowing visual observation of proper model behavior. All assumptions are tested to verify proper coding in the model. Two methods of validation are performed for the flying training model. The projected flying hours for the flying training is compared to the allotted TiS in the Programmed Flying

> Training (PFT) plan. This comparison shows the TiS from the simulation is comparable to the PFT and remains a valid representation of reality. The second method of validation is conducted by several pilot instructors as the subject matter experts (SMEs) (Rodriguez, 2007).

Faas (2003) conducted research about an Air Force sortie generation process by applying simulation model technique. In his thesis, it states that Air Force decision makers need a simulation tool to study the effects of the emerging Autonomic Logistic System (ALS) technologies on the Air Force sortie generation process. ALS is a proactive approach to logistics operations instead of current reactive approach. To analyze two systems, the discrete event simulation model, focusing on the F-16 aircraft and the radar subsystem, is developed in Arena. In his model, actual data from the F-16 radar systems are used. The sortie generation process' model provides making comparisons between the current maintenance system and the new ALS (Faas, 2003).

# III. Methodology

## Introduction

Chapter 3 focuses on how the steps of constructing the simulation model were applied to the F-16 Pilot Training process. This chapter consists of three major sections; first section focuses on assumptions, building the conceptual model and defining basic processes in the flight training, second one mentions improving the conceptual model, and third section covers the application of the seven steps of simulation modeling to the model built in Arena.

## 3.1. Assumptions

The training period in 143$^{rd}$ Oncel Squadron basically consists of two main training terms including ground training and flight training. Ground training includes the pre flight theoretical lessons, physical training and simulator training. In addition to the pre flight theoretical lessons, there are certain lectures which are planned before or during every sub phase of the flight training (INT, ACM and BFM, etc.). These lectures are also regarded as ground training. Scheduling these lectures in a timely manner is an important issue to prepare SPs for the upcoming flight phase and to make the whole course more effective. However, the ground training period is not explicitly considered in this study due to the fact that SPs are generally scheduled for these lectures at the end of flight blocks or between two flight blocks, sometimes even when flights are cancelled due to weather conditions. Another reason not to consider pre flight lessons and physical

training in the simulation model is that these training phases are not scheduled individually.

Simulator training consists of 15 missions. Nine of these simulator missions, which are supposed to be accomplished before the actual flight training period, are not taken into consideration in this study. The remaining simulator missions, which are scheduled as the actual flight training continues, are embedded into the model since they significantly affect the scheduling process as a major constraint. As a result, flight training phase and six simulator missions form the main focus of this research.

Maintenance activities are not modeled as a separate sub model in this study. It is assumed that maintenance interactions are reflected in every sortie logic patterns through abort rate and refly rate. Abort rate covers all maintenance problems which may happen between taxi and take off. Also refly rate is considered covering all instances and possibilities from SP's unsatisfactory performances to maintenance problems after take off. In addition to ideas above, spare aircraft policies are regarded as a solution to the maintenance problems before taxi. A pilot may change his/her aircraft in case of maintenance problem and continue his/her mission as planned.

## 3.2. Description of Flight Training in light of Simulation Model Concepts

The F-16 Pilot Training under the Oncel squadron structure lasts approximately 140 weekdays (7 months), 35 weekdays of this period are planned as a pre-flight ground training, and 105 weekdays as a flight training. As stated early in Chapter 2, this research's objective is to focus only on the flight training part, defined as a period

between ground training and graduation as shown at Figure 3. By considering these assumptions, model's initial time is assumed as a time when the first SP enters into flight training just after finishing the ground training.

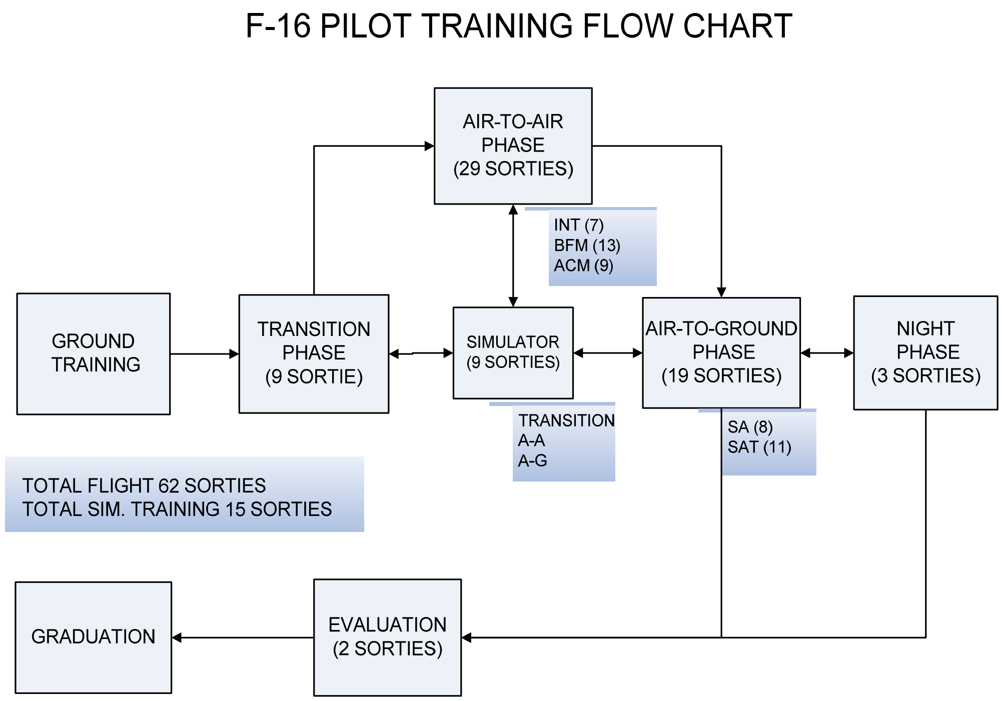



Figure 3. The Flow Chart of F-16 Pilot Training in Oncel Squadron

In a year, Oncel squadron consecutively plans to provide two separate flight trainings for two separate SP groups. There is an overlap between these two SP groups because each training period lasts approximately seven months. This overlap shows that two different groups are in the squadron at the same time approximately during the first and the last approximately one month of each training period. The following groups deal with ground training during overlapping time periods. Usually one term starts flight

training in the middle of February, the other starts in the middle of July. This circulation continues without any pause as one SP group starts flight training whenever the previous group completes flight training. These initial dates and training periods may change depending on several factors, like number of SPs, IPs, Bandits, aircraft and weather forecast.

The F-16 Pilot Flight Training period consists of three basic phases (BTR, AA, and AG) which are divided into sub phases as well. The overall flight training process, phases and sub phases are conceptually described in Figure 3. The phases' sequence, as shown at Figure 3, provides gradual progress in SP's proficiency as he/she accomplishes missions which vary from basic aircraft handling missions to more complex missions. As stated in Oncel squadron syllabus, the first objective of all activities in the squadron is to train student pilots who fly an F-16 at its full performance with excellent knowledge and flight safety. To reach this objective, every SP is normally scheduled to fly 62 sorties within flight training. Each phase and sub phase of flight training has a certain number of flights stated in the syllabus. Sortie quantities at each phase and sub phase are shown in Table 3.

Table 3. Sortie Numbers in each phase and sub phase

| BTR | AIR TO AIR | | | AIR TO GROUND | | NIGHT | EVALUATION | | |
|---|---|---|---|---|---|---|---|---|---|
| | INT | BFM | ACM | SA | SAT | | IQ | TQ | TOTAL |
| 9 | 7 | 13 | 9 | 8 | 11 | 3 | 1 | 1 | 62 |

In every phase and sub phase, each sortie can be regarded as a prerequisite for the next sortie except for night phase sorties. Night training sorties can be scheduled along

with the AG phase. Eventually an SP cannot be scheduled for a sortie without accomplishing the previous one. Besides actual sorties, each SP is required to accomplish 15 simulator flights, the first six which are scheduled before flight training phase as mentioned in the previous section. Then the last nine simulator missions are scheduled between actual sorties as proposed in the syllabus. Table 4 shows the simulator mission number and the sortie number at which a particular simulator mission is required to be completed.

Table 4. Simulator missions

| Simulator Training | | |
|---|---|---|
| No | Time | Prerequisite |
| SIM-7 | 1.20 | TR-8 |
| SIM-8 | 1.20 | INT-1 |
| SIM-9 | 1.20 | INT-1 |
| SIM-10 | 1.20 | INT-1 |
| SIM-11 | 1.20 | INT-5 |
| SIM-12 | 1.20 | INT-5 |
| SIM-13 | 1.20 | SA-1 |
| SIM-14 | 1.20 | SA-2 |
| SIM-15 | 1.20 | SAT-1 |

While flight training period continues, SPs are required to complete nine simulator missions as shown at Table 4. At this point, another important scheduling factor arises for simulator flights as well as sortie scheduling. As a squadron training rule, an SP can not be scheduled for a simulator mission without accomplishing the previous

one which is regarded as a prerequisite. In the syllabus, each of nine simulator missions is stated as a prerequisite for a certain sortie, thus each mission is required to be accomplished before pre-stated sortie. As seen from Figure 3, BTR, AA, and AG phases have a certain number of simulator missions which need to be scheduled before certain sorties. During these phases, simulator missions should be scheduled consecutively as well as actual flights. However, scheduling constraints for simulator missions are not as strict as the ones for actual sorties. Simulator missions are not supposed to be scheduled immediately before a sortie whose syllabus events dictate that certain simulator mission as a prerequisite. Instead, they can be scheduled at any other feasible time before the appropriate sortie. From the scheduler's perspective, simulator mission scheduling is regarded more flexible than actual flight scheduling. In most cases, SPs are first scheduled for the sorties on the following day's flight program, and then any SPs, who are not assigned to fly, are considered for simulator flights.

Before describing the conceptual model, it is important to mention the practical daily objective of the 143rd Oncel squadron. Figure 4 shows that Oncel squadron is responsible for producing two schedules for each following day by considering available resources, including IP, Bandit, aircraft, runway and simulator. Before squadron staff leave the squadron, the flight and simulator mission schedules are prepared and published everyday by the scheduler (IP or Bandit) who is assigned to the scheduling section of the Oncel squadron.

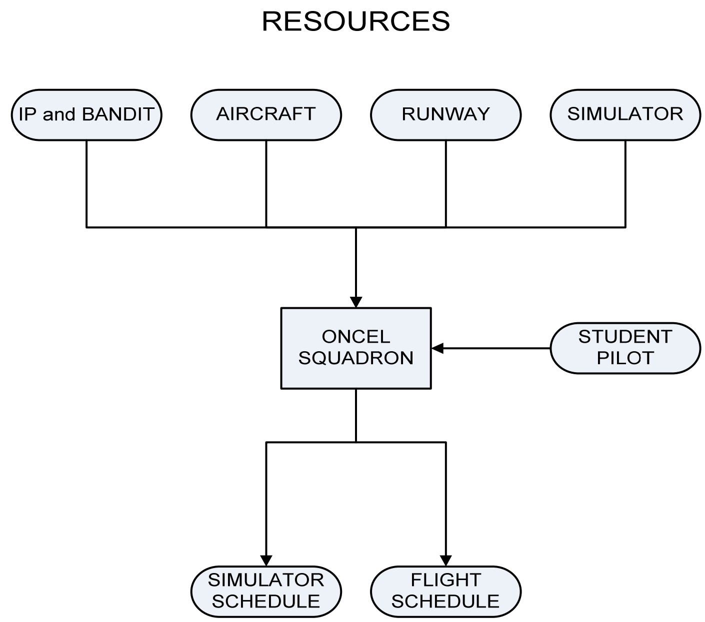



Figure 4. System's Inputs and Outputs

### 3.3. Conceptual Model through Full Model

A conceptual model needs to consider every process and interaction of the system under study. The conceptual model for the F-16 Pilot Training was built after reviewing the squadron's syllabus and gathering sufficient information covering the entire training period. At first, the conceptual model is structured simply as recommended in many simulation articles. Then the model is developed in more detail to capture all steps that are considered crucial and critical factors in the system.

Before stepping forward to build the conceptual model, the model's key factors, consisting of entity and resources, should be determined precisely. Specifying the entity type gives an answer to what flows and interacts in the model. In the Flight Training's conceptual model, a certain number of Student Pilots are created at once by the Create

module (in Arena) and disposed as a graduated pilot. On the other hand, IPs, Bandits and Aircraft are considered as model's main resources as well as the runway and simulator. Resource quantities are shown in Table 5.

Table 5. Numbers of resources

| IP | BANDIT | F-16C | F-16D | RUNWAY | SIMULATOR |
|---|---|---|---|---|---|
| 20 | 10 | 20 | 8 | 1 | 1 |

Additional details are required for our IP and Bandit resources. IP is a pilot who is authorized to fly an F-16D (double seat model) with an assigned SP within the training period. A Bandit is a pilot who is authorized to fly supportive missions within missions scheduled for SPs. A Bandit is not allowed to be scheduled with an SP for sorties which require F-16D aircraft. In the Oncel squadron syllabus, all requirements, including number of aircraft to prerequisites, are stated precisely for every mission.

After specifying basic units in the simulation model, all processes and interactions, which may take place during a usual training day, should be considered thoroughly and reflected sufficiently into the simulation model. What an SP does in the squadron during a usual day highlights the basic structure of the model. If an SP is scheduled for a sortie, he/she is supposed to meet all the requirements the day before as listed in the syllabus. In the flight day's morning following the mass briefing, an SP joins a pre-flight briefing with his/her assigned IP two hours before take off. They step from the squadron at least 30 minutes before take-off time. After flight, the IP and SP debrief

and critique the sortie. These phases, regarded as sub processes of a mission, are included in the definition of a sortie. Among the Air Force community, "A sortie starts with pre-briefing and ends with debriefing" is a well-known quote concerning sortie definition. In the conceptual model, a sortie is defined as the entire process covering pre-briefing, flight and debriefing. One sortie lasts approximately 4 hours which includes 1 hour pre-flight briefing, .5 hour preparation, 1.5 hour flight, and 1 hour debriefing.

### 3.3.1. Basic Sortie Flow in Transition Phase

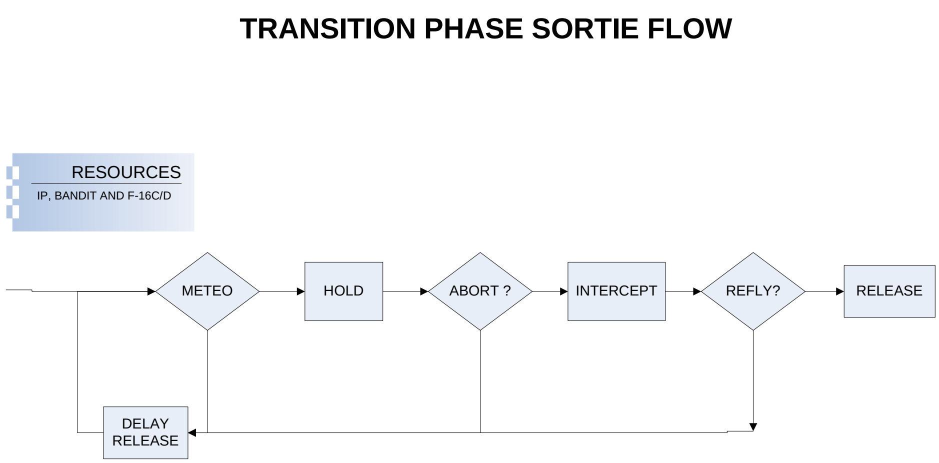



Figure 5. 2-ship Sortie in the Conceptual Model

A basic sortie is conceptually designed as shown in Figure 5. This sortie flow diagram changes slightly because sortie content differs according to each training phase. These changes will be stated in the following sections. Conceptually this sortie flow diagram can be applied for 2-ship missions in every phase.

A daily flight schedule and simulator schedule are prepared primarily by considering resource constraints, SPs' needs, and training effectiveness. In a daily schedule, available resources, consisting of IP, Bandit, aircraft and simulator are allocated as effectively as possible to each SP according to his/her need, sortie level and current status of the entire training. For each SP, resource allocation is done by adding a Seize module and specifying resource requirements stated in the syllabus for every sortie as shown in Figure 6.

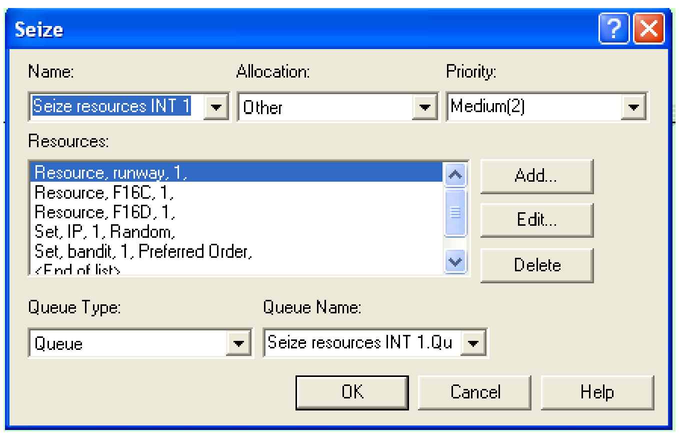



Figure 6. Resource allocation for 2-ship sortie

As a training principle, an SP scheduled for a sortie, is responsible to prepare all required items in the syllabus before the pre-flight briefing. Regardless of the weather condition, IP and SP get together for pre-flight briefing and all syllabus items are mentioned and discussed thoroughly. At the end of the pre-flight briefing, current and future forecast reports, which are available at the flight desk, are checked carefully before stepping out from the squadron. Although the weather factor is mentioned in the

following sections, it may be appropriate at least to give a short description here. Weather factor is inserted into model as a separate sub model which provides monthly rates based on the days when sorties are accomplished over two years.

If the flights are not cancelled, IP and SP step out at the specific time depending on current flight training phase and take-off following ground procedures. As shown in Figure 5, abort logic comes after weather and seize module as a second decision factor. Abort is defined as an action to cancel the sortie due to a maintenance problem during taxi or take-off. From the flight safety and squadron rules' perspective, it is not recommended to get a spare aircraft due to failure after starting taxi.

Following the flight and landing, SP and IP debrief and critique the mission in order to analyze the positive and/or negative events concerning the sortie. Process module is used as a delay to simulate entire sortie duration including pre-flight briefing, flight period, and debriefing which is assumed to be distributed uniformly between 3.75 and 4.25 hours. A sortie is modeled in this fashion because the sub events are not points of interest for this study.

At the end of the debriefing, IP may decide that SP should be rescheduled for that sortie due to his/her performance or bad weather condition, etc. In the Oncel training syllabus, it is stated the squadron re-flies eight percent of its sorties throughout each training term. This rate is reflected in the model by adding a Decide module after the Sortie Process module. In Figure 5, a Delay module is used to prevent SPs from flying more than one sortie in a day. As a squadron rule, SPs are scheduled for just one sortie in a day, except for some sorties and special conditions. At the end of basic sortie flow,

resources seized at the beginning of sortie are released by adding a Release module (TUAF SOP).

### 3.3.2. Basic Sortie Flow with 4-ship Flight

Certain sorties, especially after transition flight phase, require 4-ship flight scheduling as indicated in the squadron syllabus. These 4-ship missions are reflected in the conceptual model as shown at Figure 7.

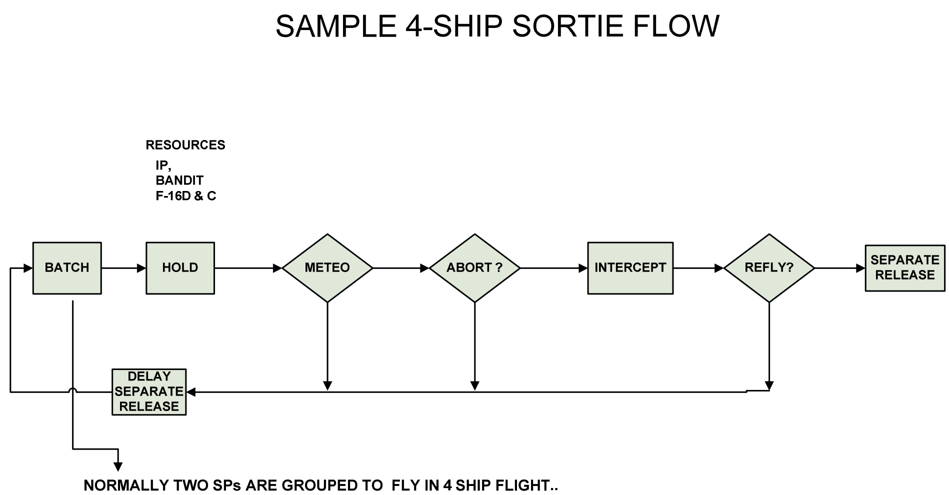



Figure 7. 4-ship Sortie in the Conceptual Model

In flight training, there are two types of 4-ship sorties. The first one requires 4-ship scheduling specifically during 2vs2 intercept phase. The second one encourages 4-ship scheduling, however it has flexibility to select between 2-ship and 4-ship scheduling based on number of SPs waiting for the same sortie or resource levels (specifically during SA and SAT phases). This flexibility, which prevents unnecessary waiting time if an SP

is behind in their training or there is no other SP to be batched, is reflected in 4-ship sortie logic except for the Intercept phase.

Resources seized by SPs during 4-ship sorties are also considerations. In the syllabus, the requirements and prerequisites for each sortie are stated in detail to include how many F-16 C/D model aircraft, SPs, IPs and Bandits should be scheduled. Generally SPs who are at the same sortie level, are scheduled in doubles for the 4-ship required mission throughout the Intercept, SA and SAT sub phases. The application of this rule provides significant savings in terms of resources and effective allocation. For example, INT-5 sortie, a 4-ship mission, requires 3 bandits as support pilots, 1 IP, 3 F-16 C and 1 F-16 D aircraft as shown at Figure 8. These resources are allocated for just one SP for one sortie. By scheduling two SPs concurrently, two training sorties can be accomplished using two Bandits, two IPs, two F-16 C and two F-16 D aircraft for two SPs. As a result, the scheduling method for 4-ship missions encourages batching two SPs who are at the same training level. The rest of the 4-ship sortie has the same flow as the basic transition sortie flow shown at Figure 5.

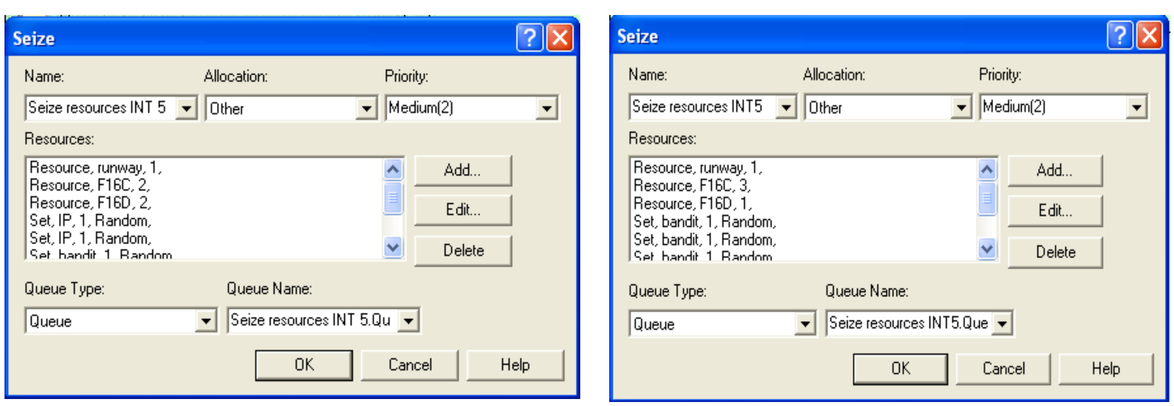



Figure 8. Allocations for 4-ship Sorties

### 3.3.3. Main Model and Sortie Logic

The main model which reflects 62 sorties and interactions between SPs and resources (IPs, Bandits and F-16 C/D) in Arena is shown at Figure 9. The main flow consists of sub models which correspond to the sub phases of the flight training program. The simulation model starts by creating a certain number of SPs and terminates when the last SP flies the last sortie of the entire training program.

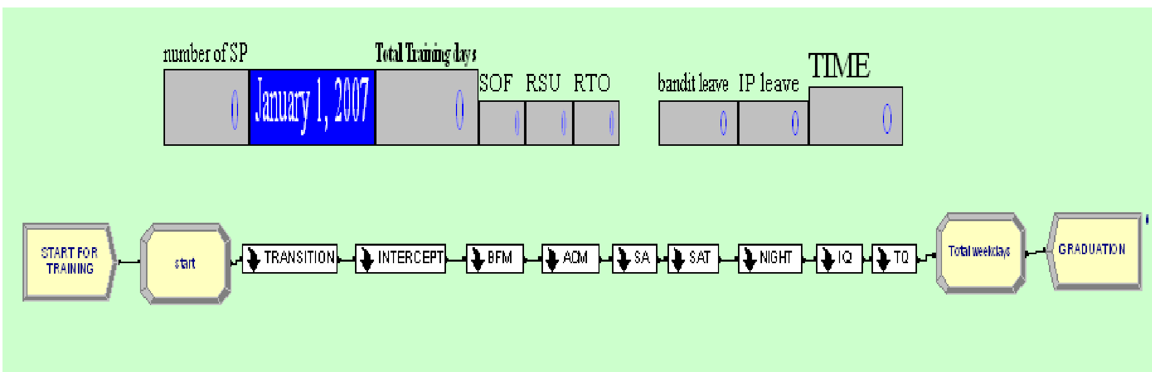



Figure 9. Main Model in Full Model

#### 3.3.3.1. 2-ship Sortie in Full Model

At the end of several modifications, 2-ship sortie logic is built as shown at Figure 10. The first part belongs to the simulator mission, and the rest describes the steps and logic for the 2-ship sortie.

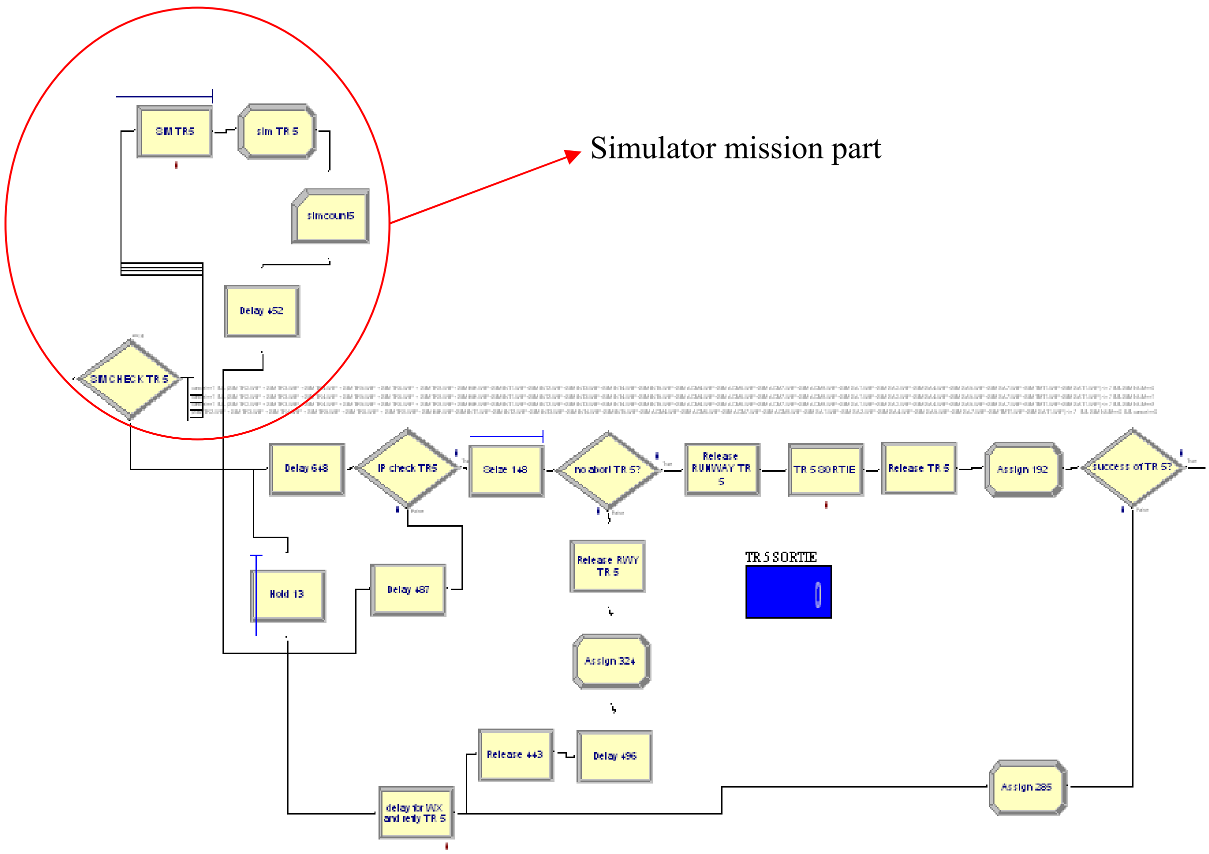



Figure 10. 2-ship Sortie in Full Model

### 3.3.3.2. 4-ship Sortie in Full Model

The 4-ship sortie logic was finalized following several reviews and verifications to meet the actual constraints for 4-ship sorties in the system as shown at Figure 11. The first is for simulator missions; the rest covers all possible situations which may occur within 4-ship sorties.

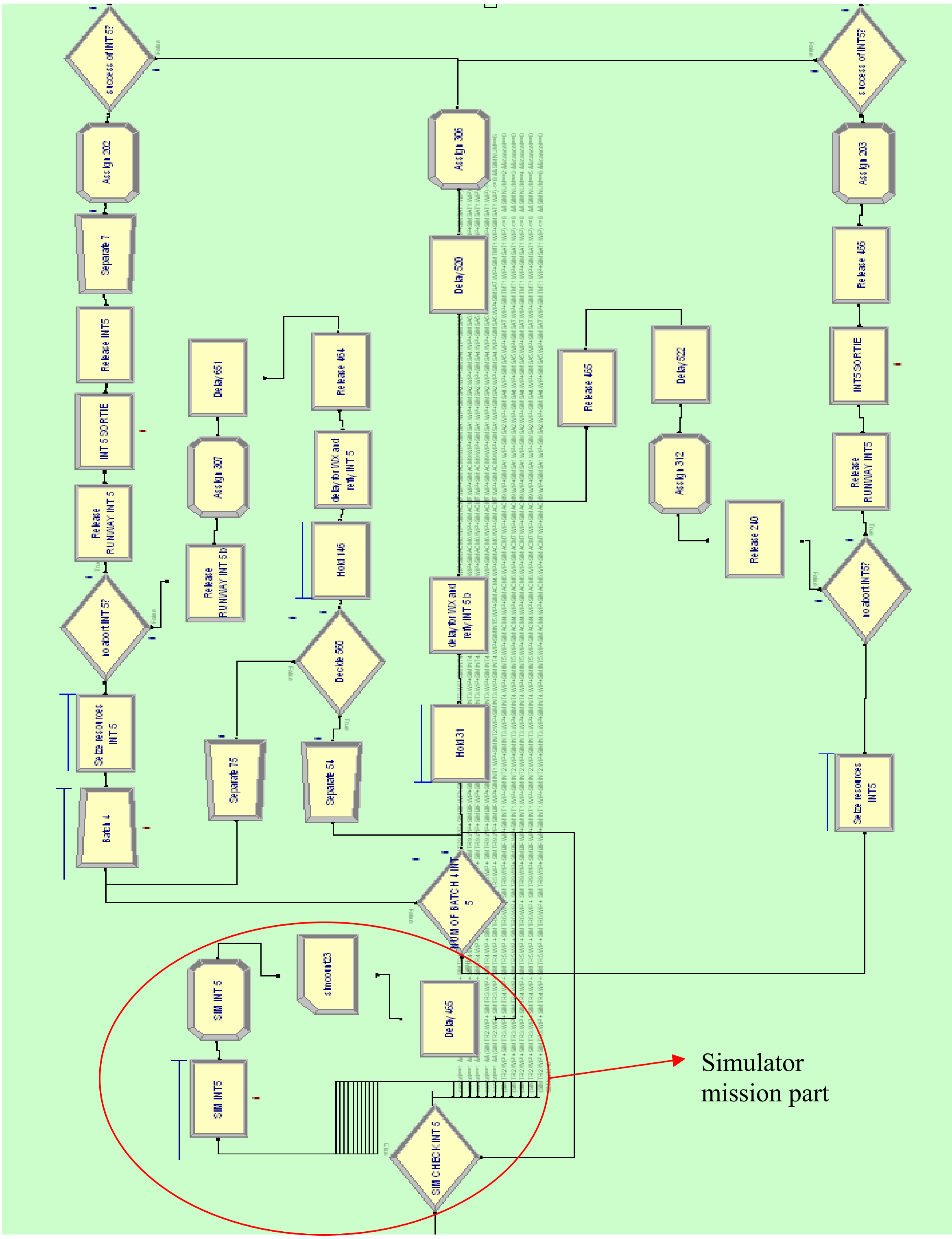



Figure 11. 4-ship Sortie in Full Model

### 3.4. Auxiliary Process Models

The flight training process is regarded as the main process within the model. There are some sub processes which contribute significant inputs and effects to the main process and are included as sub models.

#### 3.4.1. Duties during Training Period

In the Section 3.2, system resources are stated clearly. These resources, like IPs and Bandits, are used mainly for SPs' training purposes. Besides allocating these resources to the SPs, there are three additional duties that require use of these resources over the entire training period. These duties consist of Supervisor of Flight (SOF), Runway Supervisor Unit (RSU), and Range Training Officer (RTO). The scheduler must take into consideration assigning an IP or Bandit to these duties each day while allocating resources. SOF and RSU duties require authorized personnel (IP or Bandit) as long as daily flights continue over all phases. Additionally, RTO is a duty which requires authorized personnel (IP or Bandit) as long as the range area is in use. The range area is in use during the Air to Ground phase which consists of SA and SAT sub phases. Pilots, assigned to one of the duties, will be classified as unavailable in terms of flight scheduling in that sortie block.

These additional duties are implemented in the simulation model by adding a separate Create Module for each duty type. Entities are defined as duties which are created periodically and follow logic to check the duty schedule, flight schedule and flight cancellation, for every predetermined period. This logic prevents assigning

resources (IP and/or Bandit) while there is no flight activity. The sub models are shown in Figures 12 through 14 for all three duties. Since 143rd Oncel squadron is not the only squadron stationed at Akinci AFB, these three duties are allocated equally between squadrons by considering the number of flight blocs (Kayhan, 2007). Although there are some rules in allocating the duties between squadrons, any squadron may request immediate change in scheduling due to sudden personnel constraints. By considering all these ideas, the overall duty rate of the Oncel squadron is taken and inserted into the model.

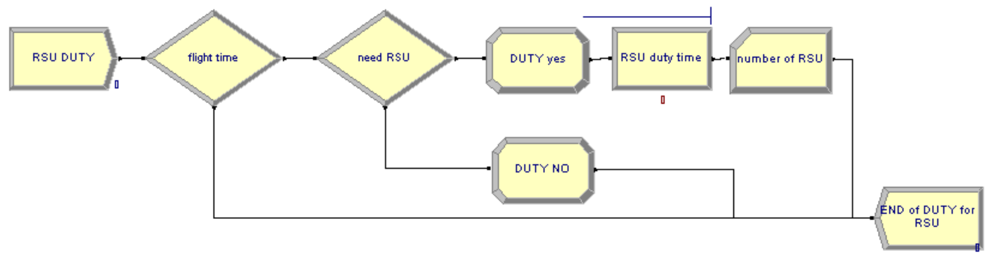



Figure 12. Design in Arena for RSU

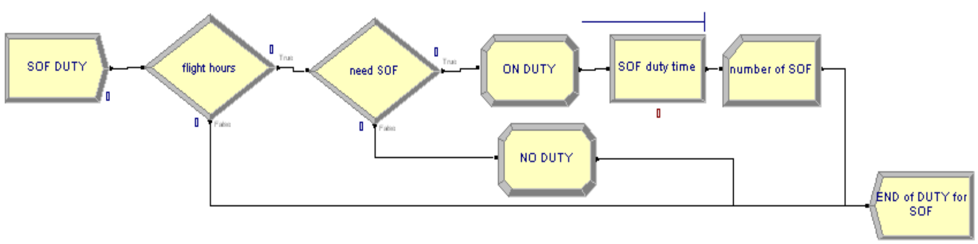



Figure 13. Design in Arena for SOF

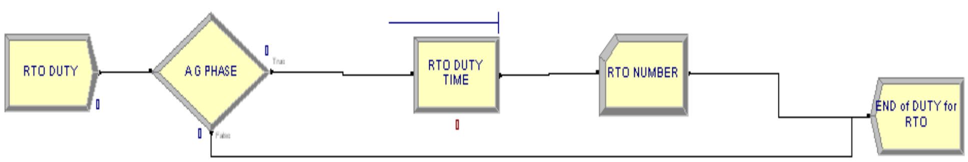



Figure 14. Design in Arena for RTO

### 3.4.2. Annual Leave for IPs and Bandits

Another significant factor which should be considered in the model is the number of personnel on leave during the training period. Normally IPs and Bandits are the only personnel whose leave status may affect the system, since SPs do not have the ability to take leave except under special conditions which are not considered within the simulation model.

A person is allowed to take as much as 1 month of leave in a year. Although there is no strict rule in scheduling off days, it is preferred that personnel take smaller periods of leave, like ten days in winter and the rest in summer. These days include weekends, so there are 8 weekdays off for winter term and 14 weekdays for summer term. Since the simulation runs without considering weekends and schedules are determined according to weekdays, 8 and 14 weekdays are used in the Leave sub model.

It is obvious that the number of the personnel on leave affects how many daily sorties can be flown. To minimize these effects, there are some regulations to follow regarding leave. The most important rule affecting our model limits the number of personnel on leave to 25 percent of total personnel. Consequently, the number of personnel on leave is not allowed to exceed 25 percent of all personnel (IPs and Bandits).

Two different Leave sub models, one for IPs and one for Bandits, are added into the simulation model with similar logic because IPs and Bandits have different responsibilities in the squadron. The limitations mentioned above are reflected in the simulation model by various formulations and modules. Time periods for winter and summer are defined and a certain number of entities, equal to the total number of IPs and

Bandits, are created once and circulated between winter and summer leave processes until meeting predefined conditions and then disposed after using total amount of leave days. As an initial condition, half of the personnel are considered that they had used their winter leaves during the previous year's winter period because the simulation model is designed to start running at the middle of winter period. An additional constraint relating to the Transition phase requires every SP to fly most of their sorties with the same IP. So IPs are not allowed to take leave during the Transition phase. On the other hand, there is no similar limitation for Bandits.

In the model after creating leave entities periodically, 25 percent rate limitation is checked via the Decide module as shown in Figure 15. Simulation time is also checked for IPs to be sure that the Transition phase is completed. Every leave entity is allowed to seize one of the resources (IP or Bandit) during certain periods (8 or 14 weekdays) according to the simulation's days. At the end of winter (summer) leave, the entity enters into a loop to scan for necessary conditions to take summer (winter) leave as well. Finally, the leave entity is disposed of after taking 22 weekdays of leave.

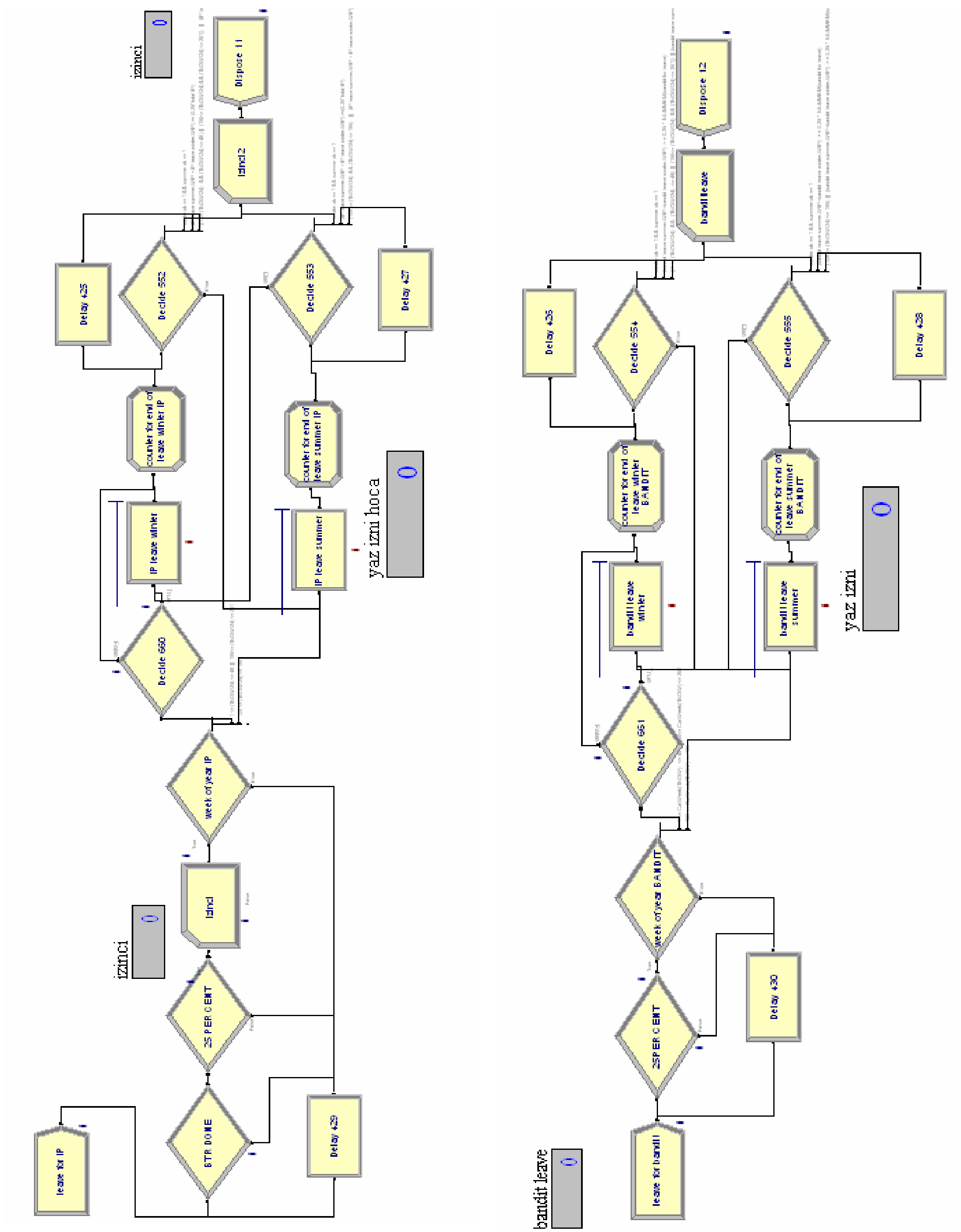


Figure 15. Sub model for leave policy (for IP and Bandit)

### 3.4.3. Daily Weather Condition Checks

As mentioned early in this chapter, weather conditions are another significant factor to include in the model. Clearance to start daily flights is strongly dependent on the weather forecast. Flight cancellations due to holidays are included in the weather factor. Sorties should be accomplished under reasonable weather conditions as much as possible, especially during initial phases.

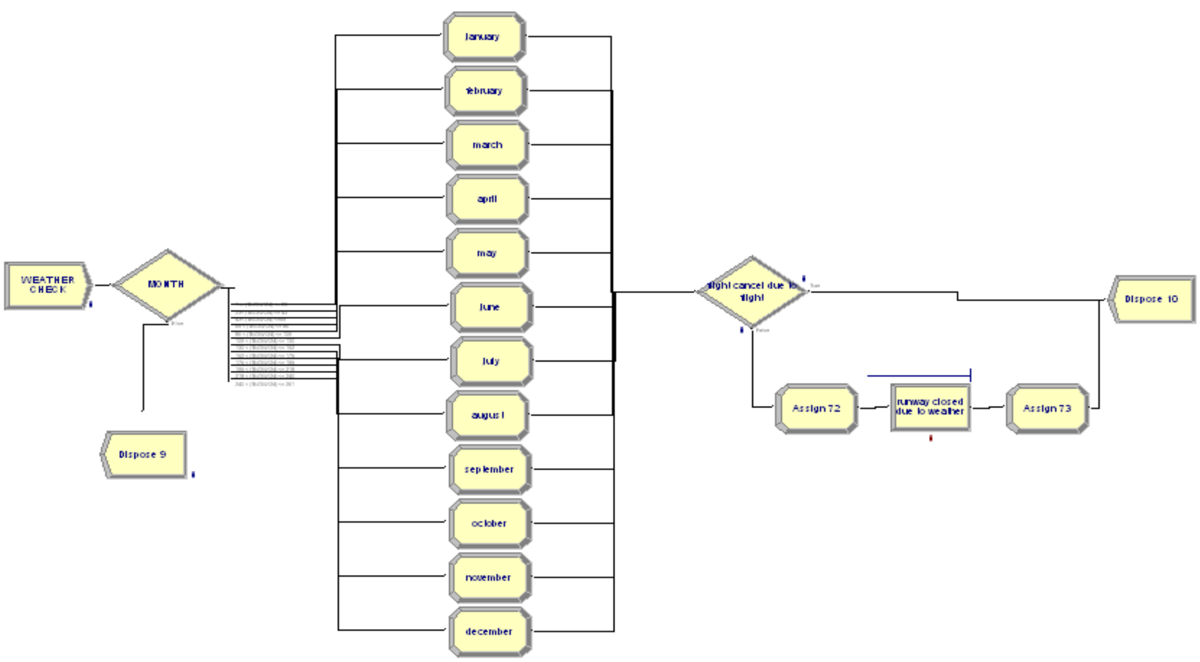



Figure 16. Sub model for weather factor

As shown at Figure 16, the weather forecast is embedded into the model by adding a Create module which creates 'daily forecast check' entities before the daily flights start. The entity passes through one of the 12 Assign modules representing the

current simulation month. The entity is assigned a monthly weather abort rate based on proportion of weather cancellations for that month over the past two years. This rate is defined as a variable and used as a decision factor to cancel the flights or not. For cases where the flights are cancelled, the runway is seized for the whole day, allowing no activity.

### 3.4.4. Simulator Flights

Simulator flights form one of the important phases of the entire training period to include the flight training phase. Within the F-16 Pilot training course, there are 15 simulator flights which are distributed between actual sorties in order to let the SPs become familiar with procedures and responsibilities on forthcoming flight phases or particular sorties. All simulator mission scheduling constraints are precisely stated in the syllabus. The model deals with the nine simulator schedules after flight training starts. These nine simulator missions and sorties to which these simulator missions are specified as prerequisite are listed in Table 4 at the beginning of this chapter. Because there is only one simulator unit on base, one SP and one IP or Bandit are scheduled for each simulator mission. In the model, the simulator unit’s schedule allows seven missions in a day. The simulator unit and assigned pilots, IP or Bandit, are considered as resources for simulator missions. Simulator mission model is combined with the main model by attaching it at the beginning of certain flight sorties.

### 3.5. Sub Model for Statistics

Within the simulation model, several statistics are collected and used for various intentions. In addition to statistics defined in Arena statistic section, a separate sub model is built to collect daily sorties, abort and refly numbers, and this data is used to verify whether the parameters are reasonable or not. This sub model is embedded into the simulation model as shown at Figure 17.

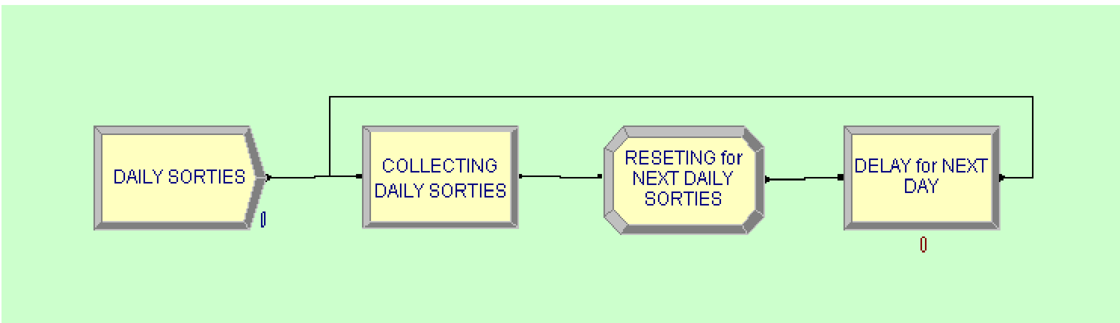



Figure 17. Daily sorties flown

### 3.6. Attributes and Variables

In this section the attributes and variables used throughout the model and in collecting some statistics are listed and explained briefly in Table 6. These attributes and variables are used as part of the logic throughout the simulation model and the flight training process with a sufficient level of detail.

Table 6. Variables and attributes in the model

| | |
|---|---|
| pass | Used as a counter to count SPs during certain sortie |
| lastSP | To specify the last SP |
| status of SOF (0 or 1) | SOF current duty status and provide scheduling logic |
| status of RSU (0 or 1) | RSU current duty status and provide scheduling logic |
| RTO STATUS (0 or 1) | RTO current duty status and provide scheduling logic |
| total SP | quantity of total student |
| abort rate | value for abort rate |
| refly rate | value for refly rate |
| total IP | quantity of total IP |
| total BANDIT | quantity of total Bandit |
| current leave summer BND | number of Bandit currently on leave during summer |
| current leave winter BND | number of Bandit currently on leave during winter |
| current leave summer IP | number of IP currently on leave during summer |
| current leave winter IP | number of IP currently on leave during winter |
| Weather (0 or 1) | monthly rate for flight according to weather condition |
| Cancel (0 or 1) | indication of whether flights are cancelled or not. |
| Spnumber | given initial number of SP in flight training |
| ip assign | IP allocation during Transition phase |
| Ipindex | IP index used in Transition phase to allocate IP |
| duration | total number of days to complete the training period |
| TR (1,..,9) | counter for Transition sorties |
| Intercept (1,..,7) | counter for Intercept sorties |
| bahc1 | counter for aircraft handling sortie |
| Bfm (1,..,12) | counter for BFM sorties |
| Acm (1,..,9) | counter for ACM sorties |
| tmt | counter for TMT sortie |
| Sa (1,..,7) | counter for SA sorties |
| Sat (1,..,5) | counter for SAT sorties |
| Sta (1,..,2) | counter for STA sorties |
| Arec (1,..,2) | counter for AREC sorties |
| Cas (1,2) | counter for CAS sorties |
| ntr1 | counter for NTR sortie |
| Ni (1,..,2) | counter for NI 1 and NI 2 sorties |

### 3.7. Verification and Validation of the Model

Verification is the step to check the model and logic to ensure they are implementing what is intended. Various verification techniques are mentioned sufficiently in Chapter 2. In this section, our focus is on the application of verification methods for the model. First it is appropriate to mention again that verification should not be considered as a step which is applied once while building a model. It is an ongoing process where a modeler uses various techniques throughout construction of the model.

The animation feature in Arena is one of the major techniques used to verify the model. Whenever additional logic or a new sub model is inserted, the simulation is run with animation enabled in Arena to check for the proper flow of entities and use of resources. Arena has other useful features such as dynamic variables to count entities at specific points. These counters are embedded into the model to check the results and verify them numerically. For instance, a dynamic variable is inserted for every flight sub phases to collect and check the number of simulator missions accomplished. The numbers from the simulation are compared with numbers obtained analytically or from the actual system. This technique is used in a number of places throughout our model.

Another verification technique is to have someone familiar with the actual system review the model. Main model and sub models were reviewed by pilots, also current AFIT students, who had attended flight training program in 143$^{rd}$ Oncel squadron to see whether the sortie flow logic 2-ship and 4-ship is correctly represented. In addition, the sub models representing the actual procedures for leave, weather and duty, were also

reviewed. Based upon feedbacks from these reviews, the model was modified accordingly.

Historical data validation and face validity are used among the validation techniques. Data from the last 12 training terms was used to validate the model. Values from the actual system and simulation model for the entire training duration differed by an average of nine weekdays which is considered reasonable. Also one pilot, who is a graduate student in the ENS department simulation track, reviewed most of the model's modification as a face validity technique.

### 3.8. Conclusion

This chapter focused on description of the system, concepts of building a simulation model and application of steps for building a simulation model. Details of our final model are discussed to include numerous figures depicting the Arena logic. In the following chapter, simulation model analysis is focused on design of experiment, regression and metamodeling.

# IV. Analysis and Results

## General

This chapter forms the final steps of this simulation study. In this chapter the main focus is concentrated on design of experiment (DOE) using the final simulation model, gathering sufficient data from simulation runs, and making an analysis to include various statistical methods. Previously in the first chapter, the main concern of this research is explained. Statistical analysis, possible techniques and arguments are discussed in Chapter 2 within the literature review. Actual construction of the simulation model and its main phases are discussed in Chapter 3. Subsequently the analysis, results and their presentation are covered in Chapter 4.

## 4.1. Design of Experiment for Simulation Model

As mentioned in the previous chapters, the 143rd F-16 Pilot Training Squadron has one performance measure and five main factors as listed at Table 7. The main factors consist of system resources and entities (SPs) which are the key players of the training system. The total time of training periods is a performance measure used as response for the system. In addition to this performance measure, IP and Bandit utilizations will be used to make inferences about some system performance.

Table 7. Main Factors

| Main Factors |
| --- |
| Instructor Pilot (IP) |
| Bandit |
| F-16 C model |
| F-16 D model |
| Student Pilot (SP) |

The first four factors are the main resources of the F-16 Pilot Training Squadron simulation model. SP is designed as a main entity in the simulation model. To figure out which factor is more significant for the response (Total Time) and how they interact between each other, a $2^k$ factorial design is implemented by using Arena's Process Analyzer. In the factorial design, *k* denotes the number of the factors. Each factor's low and high values are specified by considering the data belonging to previous training terms.  Table 8 shows the $2^5$ factorial design.

Table 8. $2^5$ Factorial Design

| Factors | Low (-1) | High (+1) |
| --- | --- | --- |
| IP | 15 | 31 |
| Bandit | 3 | 11 |
| F-16 C | 14 | 26 |
| F-16 D | 6 | 14 |
| SP | 12 | 28 |

All these design points, shown in Appendix B, are formed in Process Analyzer, and the responses including the total time of the training period and the utilizations are collected for each design point. Each scenario is run for 30 replications. This replication number was determined during the verification and validation phases because it provides enough runs to meet Central Limit Theorem conditions for approximately normal output data and also provides us with a reasonable half width. Since Total Time values are expected higher than 100 weekdays, plus and minus four weekdays half width is acceptable for our model. All design point results were checked for desired accuracy with different replication numbers by using the formula suggested by Law (2007: 501).

$$n_a^* (\beta) = \min \left\{ i \geq n: t_{i-1,1-\alpha/2} * (S^2(n)/i)^{1/2} \leq \beta \right\} \quad (1)$$

$n_a^*$ is the number of additional replications needed to achieve half width less than desired value of $\beta$. $S^2(n)$ denotes the variance with the present replication number. Also $i$ denotes the iterative increase in the number of replication.

The responses are collected after running the simulation model for all design points in Process Analyzer. The design points and responses are tabled in Appendix C. The data is initially analyzed by using three different types of plots including Interaction Plot, Main Effects Plot and Cube Plot via Minitab. Interaction plots show how two factors affect each other and the response at low and high values are shown at Figure 18. The line slope shows that the equivalent factor affects the response (Total Time) depending on the interaction factor. If the slope is steep, it means that the factor, specified at the bottom of the each sub plot, has a significant effect on the response based on the interaction with the matching factor. As seen at Figure 18, most of the subplots show

almost no gap between two lines (normal and dashed lines) corresponding to the low and the high values of the factors specified at the right side of the figure. If there is no gap between the two lines, then it can be said that the system shows no reaction to the low and high values of matching factors.

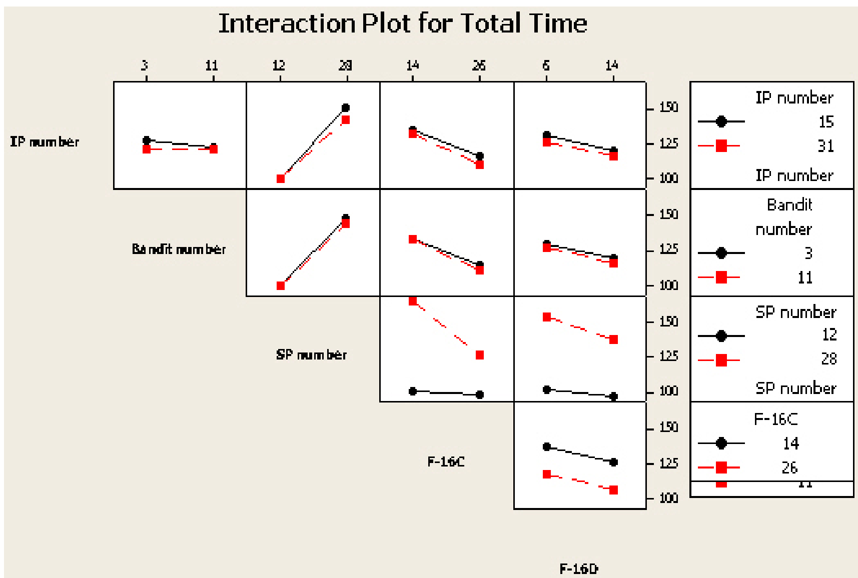



Figure 18. Interaction Plot for Total Time

There are three interaction subplots, including SP-F-16C, SP-F-16D and F-16C-F-16D interactions, which show a significant gap between the two lines.  For low SP value (12), the F-16C low and high values do not have an effect on the Total Time. Contrarily, in case of high SP value (28), both values of F-16C affect the Total Time; the low F-16C value (14) results in higher Total Time values than the high F-16C value. Same discussion can be made for the interaction between SP and F-16D factors, except the dashed line corresponding to the high SP value is less steep than the one corresponding to

the SP-F-16C interaction. This means that F-16C affects the Total Time more than F-16D for the high SP value case (28).

As it is observed, the unit scale of each factor is different. Since each line shows a linear slope and the slope determines how the corresponding factor affects the response depending on the matching factor, the unit scale does not create a problem here. Lastly as the interaction between F-16C and F-16D is examined, it is observed that there is a gap between two lines almost with the same slope. For both low and high F-16C values, the low and high F-16D values affect the Total Time with the same rate (slope). The existing gap is caused due to the effects of the low and high F-16C values over the Total Time based on the F-16D values. That is because Bandits can be replaced by an IP and an IP can fly twice in a day. In this case only the utilization values, in other words working hours, increase depending on the other resources availability.  Also it can be inferred that the system does not need more aircraft for the lower SP number cases. On the other hand, aircraft numbers become important when the SP number is high in the system. Another point is that since the system has substitution flexibilities with the Pilot resources, IP and Bandit. These factors do not have a significant effect on Total Time.

Another tool which provides visual explanations of the factor contribution to the system is main effects plot for responses. The main effects plot interpretation is valid when there is no interaction between factors. This plot is used to observe the changes in the Total Time in response to changing between each factor's low and high values. As it will be mentioned in the following sections, the interactions terms are added into the linear model of the simulation.

Another concern in analyzing the main effects plot should be on the unit scale of each factor. The intervals between low and high values of each factor are not equal as shown in Figure 19. The interval for IP and SP is 16-unit size, the one for F-16D and Bandit is 8-unit size, and the F-16C has 12-unit size interval. Since the low and high values are used for this analysis, the following comments are based on the analysis by just considering the given numerical ranges. Table 9 shows the Total Time values corresponding to the low and high values of each factor with the change per unit by considering Main Effects Plot in Figure 19.

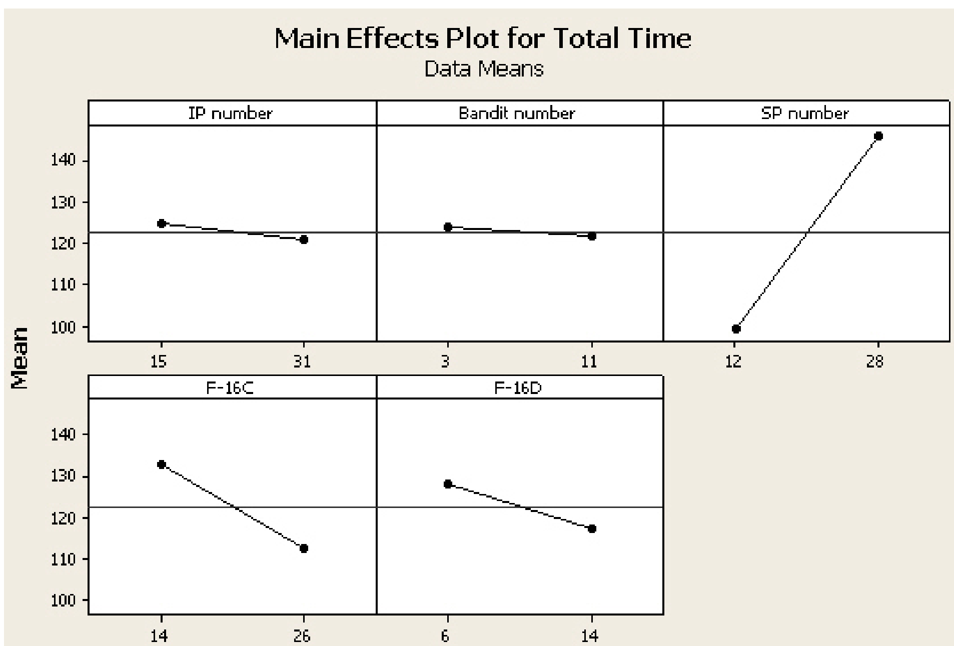



Figure 19. Main Effects Plot for Total Time

Table 9. Total Time Changes per Unit for Each Factor

| | Low | High | Change per unit (weekdays) |
|---|---|---|---|
| IP | 126.759 | 122.857 | 0.243875 |
| Bandit | 125.813 | 123.803 | 0.25125 |
| SP | 102.385 | 147.231 | -2.802875 |
| F-16C | 135.443 | 114.174 | 1.772416667 |
| F-16D | 129.54 | 120.076 | 1.183 |

Each factor's effect on a response can be separately analyzed via main effect plots. A steeper line indicates that factor has a significant effect for a performance measure (Total Time). Apparently SP has the greatest effect on Total Time of F-16 Pilot Training period. The F-16 C has the second biggest effect with F-16 D next. Finally, IP and Bandit have the least effect on the response. F-16 C contributes to the system more than F-16 D because SPs are assigned for missions requiring F-16 C; more than F-16 Ds. Almost two-thirds of all sorties require F-16 Cs.

As stated previously the system is not affected by the number of IPs or Bandits significantly because IPs and Bandits fly twice in a day, but their utilization values increase. The utilization values are shown with Time values in Appendix C. Additionally Main Effects Plots for both IP and Bandit utilizations are placed in Appendix D.

All factor combinations' effects on performance measure (Total Time) are displayed in Figure 20 called Cube Plot. This plot provides a summary of each factor effect on the response depending on every combination of resources. Practically, it is easy to see how the particular factor (resource) affects the response depending on other factors by just observing these graphs. Each row consisting of two cubes separately define the low and high F-16D values, in the same manner, each column of cubes

separately defines the low and high F-16C values. Three edges, X, Y and Z axis, of the cubes define the rest of the factors respectively IP, SP and Bandit values.

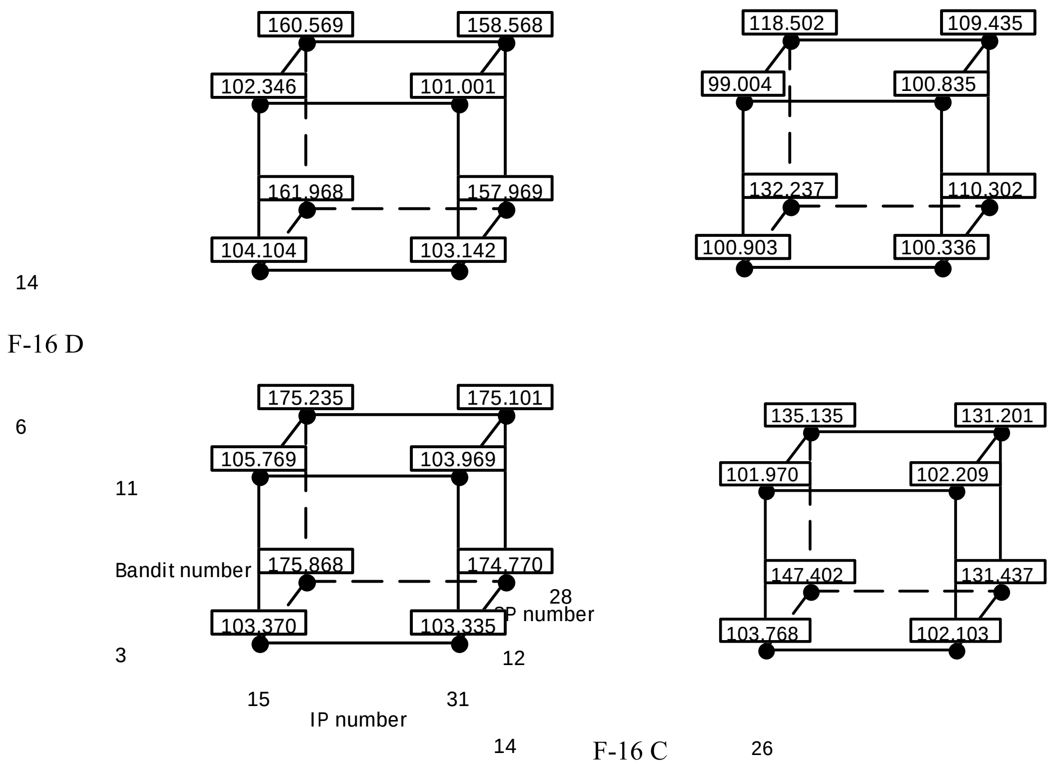



Figure 20. Cube Plot for Total Time

Cube plots, like main effect plots, are valid only if there is no interaction term. But we used this plot to reflect the DOE results visually. By just looking at the corners corresponding to Bandit values, it can be predicted that the Bandit factor is not a key player in the system because it does not show significant changes between the low and high values. The same situation is valid for the IP factor as well. As mentioned before, IPs and Bandits are allowed to fly more than one sortie which may result in higher

utilization values. In addition to this, Bandits can be replaced by any available IP in the system. This plot shows a parallelism to previous comments.

### 4.2. Metamodeling and Regression Analysis

A simulation model is considered as a black box with input data inserted and output data collected. An analyst should understand the interactions happening inside of this box. A simulation is a mathematical model of a system that may include many detailed inputs in providing outputs capturing system performance. A metamodel is defined as a model of a simulation model. In other words, a new mathematical model is built using the output data collected from a simulation model instead of using real world data (Miller, 2007). One of the reasons leading to metamodeling is the high cost of running large-scale simulation models. Secondly, time savings can be considered as another reason. For our case, non availability of the Arena software is another factor suggesting use of a metamodel. We specifically form a linear model using the outputs of our simulation model.

The factorial design is discussed as a source of data and analysis tool to provide insight about our system in the previous section of this chapter. The Multiple Linear Regression Modeling is implemented by using the data collected via DOE. The factorial design and regression techniques go hand-in-hand in building a metamodel.

The first step in regression analysis is to specify the factors and responses. Our factors (IP, Bandit, SP, F-16C, and F-16D) were determined in Chapter 3 while building our simulation model. The second step is to conduct variable selection before going

through further analysis. The stepwise technique for variable selection is applied to select which variables and interaction terms should be included in the regression analysis to build a multiple linear model. This technique indicates which factors are significant for our flight training system. An analyst wants to build a linear model which provides the same performance and still meets the same requirements with less number of factors if the model has the same adequacy.

Each factor's contribution to the R square value and the factor's individual p value are considered as the evaluation criteria during the variable selection. The p value was specified as 0.05 in this evaluation. The R square value shows the variability of the system explained by the linear model. The p value shows whether the particular factor contributes to model or not. Larger p values denote less contribution to the model and these factors are not included. At the end of variable selection, IP number is proposed to be included in the linear model since it has acceptable p value although it does not contribute to R square significantly. Unlike IP and other factors, bandit factor is considered less significant by considering its p value shown at Table 10. Although Bandit has a higher p value, it is added to the model since it changes the normality plot.

In addition to these individual factors, the interactions including SP-F-16C and SP- F-16D are observed to be significant and are included in the model. The interaction term between IP and SP is not included in the model by considering its contribution to R square. The step history for variable selection is placed in Appendix E.

Table 10. Variable selection via Stepwise Technique

| SSE | DFE | MSE | RSquare | RSquare Adj | Cp | | |
|---|---|---|---|---|---|---|---|
| 390.3 | 24 | 16.3 | 0.984 | 0.979 | 16.016295 | | |
| | | | | | | | |
| Lock | Entered | Parameter | Estimate | nDF | SS | "F Ratio" | Prob>F |
| X | X | Intercept | 19.3 | 1 | 0 | 0 | 1 |
| | X | Ip | -0.244 | 1 | 156.1851 | 7.218 | 0.0126 |
| | X | Bandit | - 0.251 | 1 | 37.6148 | 1.794 | 0.113 |
| | X | Sp | 8.01 | 3 | 18589.11 | 286.37 | 0 |
| | X | f16c | 2.24 | 2 | 6035.478 | 139.46 | 0 |
| | X | f16d | 1.2 | 2 | 1245.787 | 28.788 | 0 |
| | | (ip)*(bandit) | 0 | 2 | 64.05579 | 1.545 | 0.2347 |
| | | (ip)*(sp) | 0 | 1 | 94.17409 | 5.059 | 0.0339 |
| | | (ip)*(f16c) | 0 | 1 | 40.71178 | 1.953 | 0.175 |
| | | (ip)*(f16d) | 0 | 1 | 18.16236 | 0.834 | 0.3703 |
| | | (bandit)*(sp) | 0 | 2 | 51.79528 | 1.218 | 0.3143 |
| | | (bandit)*(f16c) | 0 | 2 | 79.25674 | 1.974 | 0.1617 |
| | | (bandit)*(f16d) | 0 | 2 | 43.4784 | 1.005 | 0.3815 |
| | X | (sp)*(f16c) | - 0.202 | 1 | 2829.476 | 130.767 | 0 |
| | X | (sp)*(f16d) | - 0.119 | 1 | 389.9447 | 18.022 | 0.0003 |
| | | (f16c)*(f16d) | 0 | 1 | 7.710664 | 0.347 | 0.5613 |

After variable selection, Multiple Linear Regression Model (MLRM) technique and Analysis of Variance (ANOVA) are implemented via the Minitab statistical package. The results and graphics are discussed next. The normality assumption is checked first because further analysis is dependent on this assumption. A plot of model residuals (Figure 21) does not show abnormal departures from normality, indicating that residuals meet the normality assumption.

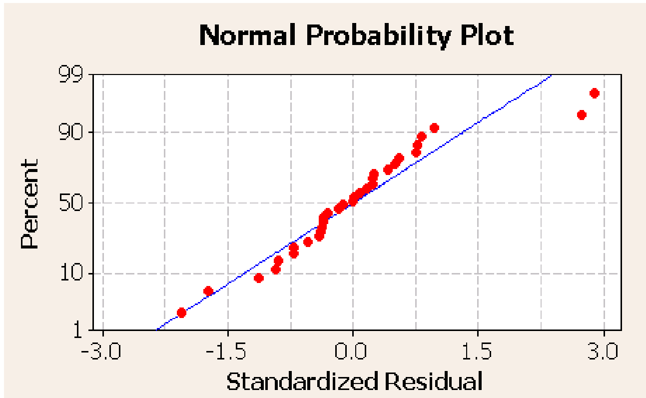



Figure 21. Normal Probability Plot

Another assumption is constant variance. This assumption can be checked by plotting residuals versus fitted values of the response. If the plot does not show any pattern like polynomial, outward tunnel or inward tunnel, then it can be inferred that constant variance assumption is met. Several residual plots were examined at the stepwise steps. For instance, the residual plot without any interaction terms showed a polynomial shape which requires transformation to a new variable into the model (Montgomery, Peck, and Vining, 2006).

The residual plot (Figure 22) was obtained by adding two interaction terms. There is no specific pattern that indicates non constant variance in this plot. However, it does not show ideal constant variance. There is an accumulation around "100" for fitted values. This accumulation originated by the simulation model results which are unresponsive to some low and high values of input data, like Bandit numbers and IP numbers (especially for the cases with low SP numbers).

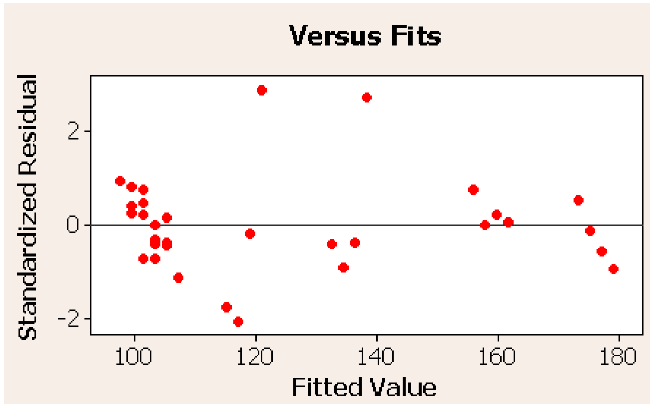



Figure 22. Plot for Residuals vs Fitted values

Also there are two fitted values which have higher residuals than others. These values belong to 7th and 8th design points that have the same resource numbers except F-16 D number. The 7th design point has six F-16 D and the 8th design point has 14 F-16 D. The Total Time values of 7th and 8th design points are underestimated. Their standardized residuals are approximately within reasonable range accepted as between -3 and 3 (Perry, 2007). Two points at the left upper part of the Normality Plot (Figure 21) and two points at the upper part of the Residual Plot (Figure 22) belong to the same design points.

Table 11. Higher Residuals in DOE Matrix

| Row | IP | Bandit | SP | F16C | F16D | Fitted | Actual | Residual | Std. Residual |
|---|---|---|---|---|---|---|---|---|---|
| 7 | 15 | 3 | 28 | 26 | 6 | 138.337 | 147.402 | 9.065 | 2.52 |
| 8 | 15 | 3 | 28 | 26 | 14 | 121.137 | 132.637 | 11.5 | 3.16 |

ANOVA provides a concise partitioning of variation from the data generated by the simulation model explained by the linear model or assigned to error (Montgomery, 2004). It also tests contribution of entire factors to the model and shows whether the

linear model is specified correctly or not. The ANOVA table (Table 12) shows that all factors together are significant for the model with a very small p value.

Table 12. Analysis of Variance for Regression Analysis

| Source | DF | Sum of Squares | Mean Square | F Ratio | Prob > F |
|---|---|---|---|---|---|
| Model | 7 | 24016.3 | 3430.9 | 210.98 | <.0001 |
| Error | 24 | 390.3 | 16.3 | | |
| C. Total | 31 | 24406.5 | | | |

Finally, the linear model is formulated to include the factors and some of their interactions which are determined during the stepwise regression analysis. Model parameter coefficients are listed at Table 13.

$$\text{Total Time} = \beta 0 + \beta 1\ (\text{IP}) + \beta 2\ (\text{Bandit}) + \beta 3\ (\text{SP}) + \beta 4\ (\text{F-16C}) + \beta 5\ (\text{F-16D}) + \beta 6\ (\text{SP*F-16C}) + \beta 7\ (\text{SP*F-16D}) \qquad (2)$$

As the coefficients of the metamodel are considered, $\beta_3$ is higher than the other $\beta$ values except constant coefficient ($\beta_0$). The SP factor previously showed up as a significant factor for the simulation model after analyzing the output data via DOE. Additionally $\beta_4$ is the next higher coefficient corresponding to the F-16C factor. This also shows a parallelism with the analysis of main effects and stepwise selection. The F-16D factor, which is less significant since the SPs are scheduled to fly more solo missions during the flight training term, follows the F-16C factor. The last two main factors, IP and Bandit, have minimum coefficients which coincide with the comments previously

made related to the utilization perspective. Also correlation between every term, including Total Time, was analyzed. The correlation between SP and Total Time is 0.81 and is the highest positive correlation. The correlation table is placed in Appendix F.

Table 13. Parameter coefficients

| | Coefficient |
|---|---|
| $\beta_0$ | 19.3 |
| $\beta_1$ | -0.244 |
| $\beta_2$ | -0.251 |
| $\beta_3$ | 8.01 |
| $\beta_4$ | 2.24 |
| $\beta_5$ | 1.2 |
| $\beta_6$ | -0.2 |
| $\beta_7$ | -0.119 |

To check the accuracy of our metamodel, ten random resource levels are selected and both simulation model and linear model are run for these ten samples. For the simulation model results, 95 % confidence intervals are calculated to see whether our metamodel's results are covered by these intervals. Results are shown at Table 14 with those cases where the models are not significantly different in bold.

Table 14. Results from the simulation model and the metamodel

| | IP | Bandit | SP | F-16 C | F-16 D | Simulation | 95 % Confidence Interval | | Model |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 15 | 6 | 13 | 24 | 6 | 109.17 | 106.886 | 111.454 | **107.542** |
| 2 | 15 | 9 | 15 | 23 | 10 | 108.06 | 105.75 | 110.37 | **110.201** |
| 3 | 23 | 7 | 21 | 21 | 12 | 115.06 | 113.034 | 117.086 | 123.393 |
| 4 | 24 | 8 | 20 | 24 | 9 | 113.89 | 112.1794 | 115.6006 | 118.776 |
| 5 | 28 | 8 | 15 | 23 | 11 | 106.93 | 105.05 | 108.81 | **106.695** |
| 6 | 28 | 8 | 23 | 25 | 14 | 113.1 | 111.221 | 114.979 | **114.172** |
| 7 | 21 | 6 | 19 | 20 | 10 | 122.67 | 120.21 | 125.13 | **123.05** |
| 8 | 21 | 5 | 21 | 23 | 9 | 126.73 | 124.22 | 129.24 | **124.36** |
| 9 | 18 | 9 | 13 | 20 | 8 | 105.27 | 103.48 | 107.05 | **106.803** |
| 10 | 19 | 8 | 25 | 26 | 9 | 122.9 | 121.01 | 124.79 | 125.171 |

Seventy percent of our metamodel results are covered by the confidence intervals from the simulation. Figure 23 displays both results together. The three values not captured by the simulation confidence intervals are higher than the simulation results. The metamodel overestimated those training periods with the given resource and SP levels. The values remain approximately three standard deviations away from the simulation results.

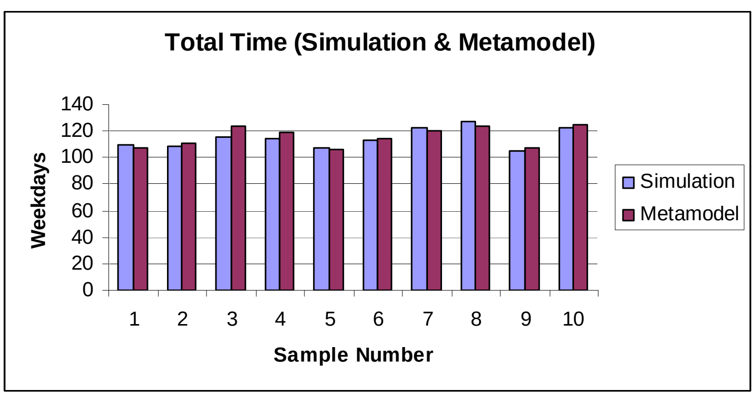



Figure 23. Total Times of Training for Two models

### 4.3. Sensitivity Analysis for Recent Resource Numbers

One of the main focuses of this study was to have an idea about acceptable limits of the system for processing increasing number of SPs with various resource levels. This type of tool provides the decision maker with an insight about system reaction when each resource level is separately increased or decreased. Specifically it may also provide an answer to the question whether the squadron can provide training to an expected number of SPs within the acceptable Total Time. The recent resource numbers from the 143rd F-16 Pilot Training Squadron are given at Table 15.

Table 15. Numbers of Resources

| Resources | Number |
|---|---|
| IP | 18 |
| Bandit | 10 |
| F-16 C | 20 |
| F-16 D | 8 |

143rd Oncel squadron completes the training in approximately 103 weekdays via the metamodel and 102 weekdays via simulation model with the given resource levels and 12 SPs. With these resource and SP numbers, the actual training lasted 99 weekdays. The analysis was conducted both by using the metamodel and the simulation model in Process Analyzer. Process Analyzer results for the simulation model are shown in Appendix G.

Since IPs and Bandits can fly twice in a day, these factors do not significantly contribute to Total Time as much as the other factors. As stated early their utilization values (working hours), given at Table 16, are increased. For this reason the factors including F-16 C, F-16 D and SP number will be examined in this analysis.

Table 16. Utilizations depending on resource levels

| IP | Bandit | SP | F-16C | F-16D | TIME | IP util. | Bandit util. |
|---|---|---|---|---|---|---|---|
| 15 | 3 | 12 | 14 | 6 | 103.37 | 0.724 | 0.898 |
| 15 | 3 | 12 | 14 | 14 | 104.104 | 0.731 | 0.874 |
| 15 | 3 | 12 | 26 | 6 | 103.768 | 0.724 | 0.878 |
| 15 | 3 | 12 | 26 | 14 | 100.903 | 0.738 | 0.861 |
| 15 | 3 | 28 | 14 | 6 | 175.868 | 0.712 | 0.831 |
| 15 | 3 | 28 | 14 | 14 | 161.968 | 0.788 | 0.869 |
| 15 | 3 | 28 | 26 | 6 | 147.402 | 0.829 | 0.923 |
| 15 | 3 | 28 | 26 | 14 | 132.637 | 0.935 | 0.97 |
| 15 | 11 | 12 | 14 | 6 | 105.769 | 0.649 | 0.381 |
| 15 | 11 | 12 | 14 | 14 | 102.346 | 0.661 | 0.378 |
| 15 | 11 | 12 | 26 | 6 | 101.97 | 0.655 | 0.384 |
| 15 | 11 | 12 | 26 | 14 | 99.004 | 0.662 | 0.374 |
| 15 | 11 | 28 | 14 | 6 | 175.235 | 0.619 | 0.378 |
| 15 | 11 | 28 | 14 | 14 | 160.569 | 0.698 | 0.407 |
| 15 | 11 | 28 | 26 | 6 | 135.135 | 0.754 | 0.471 |
| 15 | 11 | 28 | 26 | 14 | 118.502 | 0.895 | 0.51 |
| 31 | 3 | 12 | 14 | 6 | 103.335 | 0.278 | 0.86 |
| 31 | 3 | 12 | 14 | 14 | 103.142 | 0.277 | 0.82 |
| 31 | 3 | 12 | 26 | 6 | 102.103 | 0.281 | 0.824 |
| 31 | 3 | 12 | 26 | 14 | 100.336 | 0.297 | 0.772 |
| 31 | 3 | 28 | 14 | 6 | 174.77 | 0.315 | 0.781 |
| 31 | 3 | 28 | 14 | 14 | 157.969 | 0.354 | 0.822 |
| 31 | 3 | 28 | 26 | 6 | 131.437 | 0.401 | 0.891 |
| 31 | 3 | 28 | 26 | 14 | 110.302 | 0.443 | 0.948 |
| 31 | 11 | 12 | 14 | 6 | 103.969 | 0.245 | 0.367 |
| 31 | 11 | 12 | 14 | 14 | 101.001 | 0.249 | 0.371 |
| 31 | 11 | 12 | 26 | 6 | 102.209 | 0.253 | 0.357 |
| 31 | 11 | 12 | 26 | 14 | 100.835 | 0.26 | 0.352 |
| 31 | 11 | 28 | 14 | 6 | 175.101 | 0.279 | 0.36 |
| 31 | 11 | 28 | 14 | 14 | 158.568 | 0.309 | 0.385 |
| 31 | 11 | 28 | 26 | 6 | 131.201 | 0.349 | 0.446 |
| 31 | 11 | 28 | 26 | 14 | 109.435 | 0.376 | 0.476 |

First of all, the question of how many additional SPs the 143rd Oncel squadron can handle by using the same resource levels within the acceptable Total Time will be examined. As mentioned in previous chapters, there are two consecutive training periods which may affect each other if any extension occurs during the training Total Time. The acceptable delay criteria is defined to see how many additional SPs can be trained within the acceptable time limits while avoiding a major delay in the training period. The acceptable delay is determined as ten weekdays for the number of resources given in Table 15. It is expected that each additional SP increases the Total Time. The same calculation is done by using the simulation model and metamodel.

After adding one more SP to the model, the new Total Time values are recorded and shown at Table 17. As a result, each additional SP increases the Total Time by approximately three weekdays for the metamodel and two weekdays for the simulation model. In this case, an additional three SPs can be added to the training program and the Total Time will extend approximately nine weekdays. Even when the SP number is doubled, the Total Time increased with the same proportion. The system could handle double the number of SPs within six months due to the current low number of SP and sufficient number of other resources.

Table 17. Effects of Each Additional SP

| Additional SP | Simulation | Model |
|---|---|---|
| 0 | 101.73 | 102.86 |
| 1 | 103.967 | 106.82 |
| 2 | 106.436 | 109.82 |
| 3 | 108.875 | 112.82 |

Secondly the F-16 C effect to the training period will be considered. Each F-16 C reduction expectedly increases the Total Time. The new Total Time values, as determined by simulation and metamodel, are shown in Table 18 corresponding to each reduction in F-16 C number. Each F-16 C model reduction increases the Total Time by approximately one weekday for the metamodel and approximately two weekdays (on average) for the simulation model. Total Time does not extend past ten weekdays even if the squadron faces 5-unit F-16 C reductions for the simulation model. These results show that current number of F-16 C is higher than needed. Since SPs are not allowed to fly more than one sortie and there are less numbers of SPs, each reduction in F-16 Cs did not increase the Total Time significantly.

Table 18. Effect of Each Reduction in F-16 C on Total Time

| F-16 C Reduction | Simulation | Model |
|---|---|---|
| 0 | 101.73 | 102.86 |
| 1 | 102.703 | 104.008 |
| 2 | 110.067 | 104.196 |
| 3 | 109.402 | 104.384 |
| 4 | 109.736 | 104.572 |

The same steps are implemented for the F-16 D factor. The metamodel does not care whether one of the resources is zero or not since it is a linear formulation. The simulation model normally does not run under these conditions. If F-16 D number was inserted unrealistically as “0”, the simulation model would give an error. Each F-16 D reduction in the simulation model, especially in low F-16 D numbers, did not increase the

Total Time linearly. Therefore, our analysis only considers the simulation results under these circumstances. The simulation model results are shown at Table 19.

Table 19. Effect of Each Reduction in F-16 D on Total Time

| F-16 D Reduction | Simulation |
|---|---|
| 0 | 101.73 |
| 1 | 109.671 |
| 2 | 109.269 |
| 3 | 112.635 |
| 4 | 121.509 |

As a summary, this analysis showed that the squadron can handle more SPs than the current number within acceptable extension in the Total Time with the given resources. Even when the SP number was doubled, the Total Training period lasted approximately 6 months. However, utilization values were increased accordingly. The analysis results obviously depend on specified factor numbers. Therefore this case study reflects the results based on previously specified resource levels (Table 15). We also examined different scenarios with other resource levels that showed similar results.

### 4.4. Conclusion

In this chapter the data produced by the simulation model runs are analyzed to have an idea how the system reacts with different levels of resources and entities. As a summary, regression analysis techniques and metamodeling are implemented through this chapter. Additionally as visual presentation, main effects, interactions between factors and cube plots were used.

As stated in Chapter 3, there are two flight training terms in a year. The results and following analysis focus only on the first term which is held during the first 6 months of the year. The second term analysis is redundant of the first and therefore not discussed.

# V. Conclusions and Recommendations

## General

This chapter reviews the key points of this study. The previous four chapters formed the foundation of this simulation study. First a short summary of these chapters will be mentioned. Following the summary, recommendations for further research topics will be discussed.

## 5.1. Research and Conclusions

The simulation study of the F-16 Pilot Training Squadron was initiated first by defining the main interest and describing the organization and procedures of the flight training. The additional ideas, extending the coverage of this study, emerged during the construction phase of the simulation model. Subsequently design of experiment was implemented to collect necessary output data from our simulation model for following analysis. The results were presented in Chapter 4 using statistical analysis techniques.

The flight phase which is the most important phase of the entire training period was captured within the simulation model. The final simulation model does not reflect the real world exactly due to the following reasons. First of all the maintenance factors were not embedded in the Arena model. Only spare aircraft policy was generally covered. Like the maintenance factor, the personnel medical status (i.e., sickness) was not included due to lack of sufficient data. Lastly, the weather factor was embedded into the simulation model by only considering daily forecast. It is obvious that the weather status may

change temporarily, for instance the first block of flights may be cancelled due to weather conditions, but the second block of flights may continue. The aim was to come up with a model which is considered close enough to the real system.

In the analysis phase, system reaction on under certain conditions such as SP number increase, F-16 C and F-16 D decrease was investigated. Sensitivity analysis was also conducted. It was realized that SPs are the most significant factor in the system. Although IPs and Bandits are main players of the flight training, they unexpectedly did not contribute to the model as much as the other three factors due to their (IPs-Bandits) utilization factor. Unlike SPs, IPs and Bandits may be required to fly more than one sortie in a day resulting in an increase in utilization values (work hours). Also it was observed that the F-16 C is more significant than the F-16 D. As stated in the training syllabus, the solo sorties requiring F-16 C allocation are more than the dual sorties requiring F-16 D allocation. It is considered that this allocation makes the F-16 C more significant in the simulation model. The same fact was found via statistical analysis reflected as a higher coefficient in the metamodel and steeper slope in the main effect plots versus F-16 D.

By using the simulation model, a metamodel was constructed via multiple linear regression analysis. The interactions between factors were tested. It was observed that the interaction terms between SP and each F-16 type significantly contributed to the metamodel. Subsequently the sensitivity analysis was implemented for the given sample resource levels.

Each additional SP increased the Total Time more than the other factors. Each additional SP resulted in approximately two-weekday additional time to the Total Time

based on the recent resource levels. Also each additional decrease in F-16 C number resulted in approximately one-weekday extension. The F-16 D reduction affected the system in a non-linear fashion. These results vary depending on the given SP and resource levels.

### 5.2. Recommendations

The simulation model can be improved by adding logic which more accurately considers the utilization of IPs and Bandits. In the current model, utilization values are collected as a subsidiary performance measures to observe how they tend to vary. The utilization values can be embedded into the simulation model to limit the daily or weekly work hours for IPs and Bandits.

If the related statistical information is obtained, the daily medical status can be reflected in the simulation model. A medical effect to the training periods can then be analyzed to see how significant it is in the model. Also the weather factor per each block can be embedded into the model. This extension makes the simulation more realistic than the current one. But this addition requires detailed information corresponding to each block.

Another contribution to the simulation model can be made in the maintenance perspective. Maintenance effect on the current operative F-16 number may vary depending on many factors like weather, periodic maintenance, number of the maintenance staff, spare aircraft, and so forth. First only the flight training period was the point of interest of this study according to procedures stated in the syllabus. The

maintenance can be modeled as a separate part and embedded to the flight training simulation model.

## Appendix A. List of Abbreviations

| | |
|---|---|
| AA | Air to Air |
| AG | Air to Ground |
| ACM | Air Combat Maneuvering |
| AREC | Armed Reconnaissance |
| BFM | Basic Fighter Maneuvering |
| BTR | Basic Training |
| DOE | Design of Experiment |
| INT | Intercept |
| IP | Instructor Pilot |
| IQ | Instrument Qualification |
| MLRM | Multiple Linear Regression Model |
| NI | Night Intercept |
| NTR | Night Training |
| RSU | Runway Supervisor Unit |
| SA | Surface Attack |
| SAT | Tactical Surface Attack |
| SP | Student Pilot |
| STA | Surface Tactical Attack |
| TQ | Tactical Qualification |

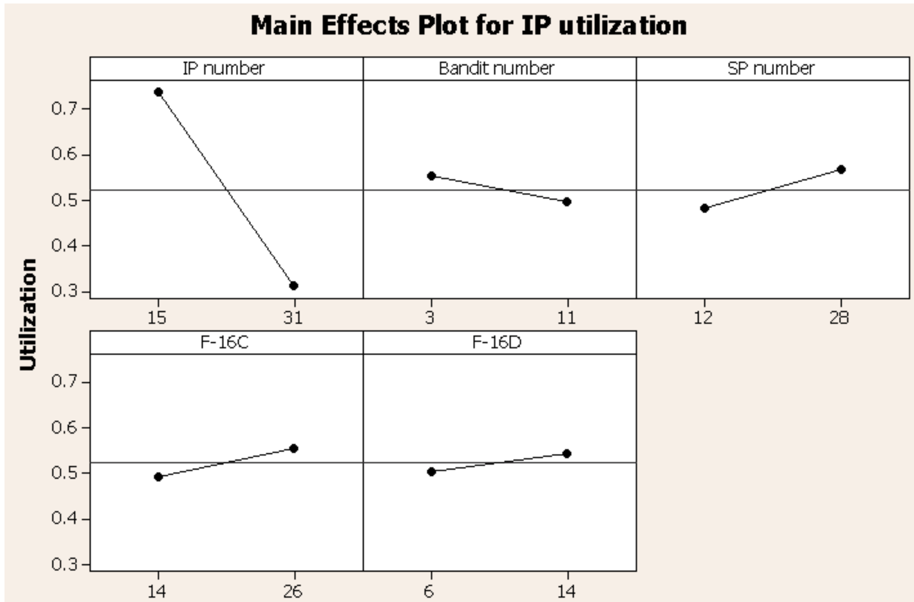
## Appendix B. Factorial Design with Coded Factors

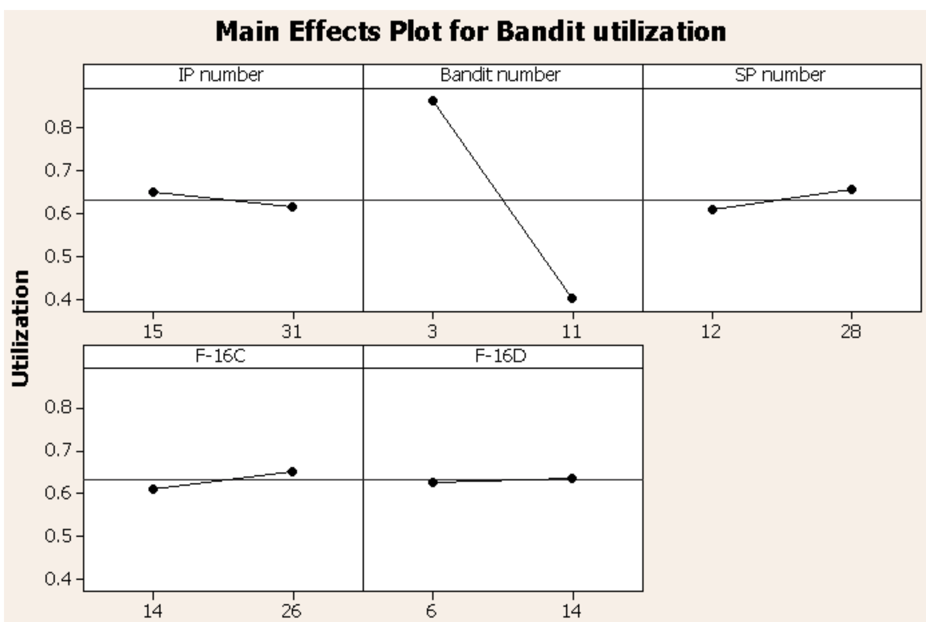
| Run | A | B | C | D | E |
|---|---|---|---|---|---|
| 1 | -1 | -1 | -1 | -1 | -1 |
| 2 | -1 | -1 | -1 | -1 | 1 |
| 3 | -1 | -1 | -1 | 1 | -1 |
| 4 | -1 | -1 | -1 | 1 | 1 |
| 5 | -1 | -1 | 1 | -1 | -1 |
| 6 | -1 | -1 | 1 | -1 | 1 |
| 7 | -1 | -1 | 1 | 1 | -1 |
| 8 | -1 | -1 | 1 | 1 | 1 |
| 9 | -1 | 1 | -1 | -1 | -1 |
| 10 | -1 | 1 | -1 | -1 | 1 |
| 11 | -1 | 1 | -1 | 1 | -1 |
| 12 | -1 | 1 | -1 | 1 | 1 |
| 13 | -1 | 1 | 1 | -1 | -1 |
| 14 | -1 | 1 | 1 | -1 | 1 |
| 15 | -1 | 1 | 1 | 1 | -1 |
| 16 | -1 | 1 | 1 | 1 | 1 |
| 17 | 1 | -1 | -1 | -1 | -1 |
| 18 | 1 | -1 | -1 | -1 | 1 |
| 19 | 1 | -1 | -1 | 1 | -1 |
| 20 | 1 | -1 | -1 | 1 | 1 |
| 21 | 1 | -1 | 1 | -1 | -1 |
| 22 | 1 | -1 | 1 | -1 | 1 |
| 23 | 1 | -1 | 1 | 1 | -1 |
| 24 | 1 | -1 | 1 | 1 | 1 |
| 25 | 1 | 1 | -1 | -1 | -1 |
| 26 | 1 | 1 | -1 | -1 | 1 |
| 27 | 1 | 1 | -1 | 1 | -1 |
| 28 | 1 | 1 | -1 | 1 | 1 |
| 29 | 1 | 1 | 1 | -1 | -1 |
| 30 | 1 | 1 | 1 | -1 | 1 |
| 31 | 1 | 1 | 1 | 1 | -1 |
| 32 | 1 | 1 | 1 | 1 | 1 |

## Appendix C. Factors and Responses from DOE

| IP | Bandit | SP | F-16C | F-16D | TIME | IP util. | Bandit util. |
|---|---|---|---|---|---|---|---|
| 15 | 3 | 12 | 14 | 6 | 103.37 | 0.724 | 0.898 |
| 15 | 3 | 12 | 14 | 14 | 104.104 | 0.731 | 0.874 |
| 15 | 3 | 12 | 26 | 6 | 103.768 | 0.724 | 0.878 |
| 15 | 3 | 12 | 26 | 14 | 100.903 | 0.738 | 0.861 |
| 15 | 3 | 28 | 14 | 6 | 175.868 | 0.712 | 0.831 |
| 15 | 3 | 28 | 14 | 14 | 161.968 | 0.788 | 0.869 |
| 15 | 3 | 28 | 26 | 6 | 147.402 | 0.829 | 0.923 |
| 15 | 3 | 28 | 26 | 14 | 132.637 | 0.935 | 0.97 |
| 15 | 11 | 12 | 14 | 6 | 105.769 | 0.649 | 0.381 |
| 15 | 11 | 12 | 14 | 14 | 102.346 | 0.661 | 0.378 |
| 15 | 11 | 12 | 26 | 6 | 101.97 | 0.655 | 0.384 |
| 15 | 11 | 12 | 26 | 14 | 99.004 | 0.662 | 0.374 |
| 15 | 11 | 28 | 14 | 6 | 175.235 | 0.619 | 0.378 |
| 15 | 11 | 28 | 14 | 14 | 160.569 | 0.698 | 0.407 |
| 15 | 11 | 28 | 26 | 6 | 135.135 | 0.754 | 0.471 |
| 15 | 11 | 28 | 26 | 14 | 118.502 | 0.895 | 0.51 |
| 31 | 3 | 12 | 14 | 6 | 103.335 | 0.278 | 0.86 |
| 31 | 3 | 12 | 14 | 14 | 103.142 | 0.277 | 0.82 |
| 31 | 3 | 12 | 26 | 6 | 102.103 | 0.281 | 0.824 |
| 31 | 3 | 12 | 26 | 14 | 100.336 | 0.297 | 0.772 |
| 31 | 3 | 28 | 14 | 6 | 174.77 | 0.315 | 0.781 |
| 31 | 3 | 28 | 14 | 14 | 157.969 | 0.354 | 0.822 |
| 31 | 3 | 28 | 26 | 6 | 131.437 | 0.401 | 0.891 |
| 31 | 3 | 28 | 26 | 14 | 110.302 | 0.443 | 0.948 |
| 31 | 11 | 12 | 14 | 6 | 103.969 | 0.245 | 0.367 |
| 31 | 11 | 12 | 14 | 14 | 101.001 | 0.249 | 0.371 |
| 31 | 11 | 12 | 26 | 6 | 102.209 | 0.253 | 0.357 |
| 31 | 11 | 12 | 26 | 14 | 100.835 | 0.26 | 0.352 |
| 31 | 11 | 28 | 14 | 6 | 175.101 | 0.279 | 0.36 |
| 31 | 11 | 28 | 14 | 14 | 158.568 | 0.309 | 0.385 |
| 31 | 11 | 28 | 26 | 6 | 131.201 | 0.349 | 0.446 |
| 31 | 11 | 28 | 26 | 14 | 109.435 | 0.376 | 0.476 |

## Appendix D. Main Effect Plots for IP and Bandit Utilizations



## Appendix E. Step History

| Step | Parameter | Action | "Sig | Seq SS | RSquare | Cp |
|---|---|---|---|---|---|---|
| 1 | ip | Entered | 0.6563 | 156.1851 | 0.0067 | 1430.4 |
| 2 | bandit | Entered | 0.8297 | 37.6148 | 0.0083 | 1430 |
| 3 | sp | Entered | 0 | 15369.69 | 0.6666 | 465.53 |
| 4 | f16c | Entered | 0.0002 | 3206.003 | 0.8039 | 265.92 |
| 5 | f16d | Entered | 0.0216 | 855.8419 | 0.8406 | 214.1 |
| 6 | (ip)*(bandit) | Entered | 0.676 | 26.44099 | 0.8417 | 214.44 |
| 7 | (ip)*(bandit) | Removed | 0.676 | 26.44099 | 0.8406 | 214.1 |
| 8 | (ip)*(sp) | Entered | 0.4281 | 94.17409 | 0.8446 | 210.18 |
| 9 | (ip)*(sp) | Removed | 0.4281 | 94.17409 | 0.8406 | 214.1 |
| 10 | (ip)*(f16c) | Entered | 0.6037 | 40.71178 | 0.8423 | 213.54 |
| 11 | (ip)*(f16c) | Removed | 0.6037 | 40.71178 | 0.8406 | 214.1 |
| 12 | (ip)*(f16d) | Entered | 0.7292 | 18.16236 | 0.8413 | 214.96 |
| 13 | (ip)*(f16d) | Removed | 0.7292 | 18.16236 | 0.8406 | 214.1 |
| 14 | (bandit)*(sp) | Entered | 0.7597 | 14.18048 | 0.8412 | 215.21 |
| 15 | (bandit)*(sp) | Removed | 0.7597 | 14.18048 | 0.8406 | 214.1 |
| 16 | (bandit)*(f16c) | Entered | 0.5996 | 41.64194 | 0.8423 | 213.48 |
| 17 | (bandit)*(f16c) | Removed | 0.5996 | 41.64194 | 0.8406 | 214.1 |
| 18 | (bandit)*(f16d) | Entered | 0.8442 | 5.8636 | 0.8408 | 215.73 |
| 19 | (bandit)*(f16d) | Removed | 0.8442 | 5.8636 | 0.8406 | 214.1 |
| 20 | (sp)*(f16c) | Entered | 0 | 2829.476 | 0.9617 | 38.172 |
| 21 | (sp)*(f16d) | Entered | 0.0002 | 389.9447 | 0.9784 | 15.651 |
| 22 | (f16c)*(f16d) | Entered | 0.5556 | 7.710664 | 0.9788 | 17.166 |
| 23 | (f16c)*(f16d) | Removed | 0.5556 | 7.710664 | 0.9784 | 15.651 |
| 24 | bandit | Removed | 0.193 | 37.6148 | 0.9768 | 16.016 |
| 25 | ip | Removed | 0.0126 | 156.1851 | 0.9701 | 23.838 |
| 26 | ip | Entered | 0.0126 | 156.1851 | 0.9768 | 16.016 |

# Appendix F. Correlations between Metamodel Factors

| | *IP* | *Bandit* | *SP* | *F-16C* | *F-16D* | *SP*F-16C* | *SP*F-16D* | *SP*IP* | *TIME* |
|---|---|---|---|---|---|---|---|---|---|
| IP | 1 | | | | | | | | |
| Bandit | 0 | 1 | | | | | | | |
| SP | 0 | 0 | 1 | | | | | | |
| F-16C | 0 | 0 | 0 | 1 | | | | | |
| F-16D | 0 | 0 | 0 | 0 | 1 | | | | |
| SP*F-16C | 0 | 0 | 0.777 | 0.583 | 0 | 1 | | | |
| SP*F-16D | 0 | 0 | 0.680 | 0 | 0.680 | 0.529 | 1 | | |
| SP*IP | 0.634 | 0 | 0.729 | 0 | 0 | 0.567 | 0.496 | 1 | |
| TIME | -0.071 | -0.036 | 0.812 | -0.384 | -0.170 | 0.326 | 0.399 | 0.532 | 1 |

## Appendix G. Process Analyzer Results for Sensitivity Analysis

| IP | Bandit | SP | F-16 C | F-16 D | TIME |
|---|---|---|---|---|---|
| 18 | 6 | 12 | 20 | 8 | 101.745 |
| 18 | 6 | 13 | 20 | 8 | 102.343 |
| 18 | 6 | 14 | 20 | 8 | 103.236 |
| 18 | 6 | 15 | 20 | 8 | 105.467 |
| 18 | 6 | 16 | 20 | 8 | 106.869 |
| 18 | 6 | 17 | 20 | 8 | 108.668 |
| 18 | 6 | 18 | 20 | 8 | 108.135 |
| 18 | 6 | 19 | 20 | 8 | 109.302 |
| 18 | 6 | 20 | 20 | 8 | 112.935 |
| 18 | 6 | 21 | 20 | 8 | 115.168 |
| 18 | 6 | 22 | 20 | 8 | 116.935 |
| 18 | 6 | 23 | 20 | 8 | 118.571 |
| 18 | 6 | 24 | 20 | 8 | 121.37 |
| 18 | 6 | 25 | 20 | 8 | 125.503 |
| 18 | 6 | 30 | 20 | 8 | 140.267 |
| 18 | 6 | 35 | 20 | 8 | 155.468 |
| 18 | 6 | 40 | 20 | 8 | 170.3 |
| 18 | 6 | 12 | 19 | 8 | 102.703 |
| 18 | 6 | 12 | 18 | 8 | 110.067 |
| 18 | 6 | 12 | 17 | 8 | 109.402 |
| 18 | 6 | 12 | 16 | 8 | 109.736 |
| 18 | 6 | 12 | 15 | 8 | 111.335 |
| 18 | 6 | 12 | 14 | 8 | 110.103 |
| 18 | 6 | 12 | 13 | 8 | 112.903 |
| 18 | 6 | 12 | 12 | 8 | 116.809 |
| 18 | 6 | 12 | 11 | 7 | 122.935 |
| 18 | 6 | 12 | 20 | 7 | 109.671 |
| 18 | 6 | 12 | 20 | 6 | 109.269 |
| 18 | 6 | 12 | 20 | 5 | 112.635 |
| 18 | 6 | 12 | 20 | 4 | 121.509 |

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## Vita

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**14. ABSTRACT**

The need for fighter pilots in the Turkish Air Force is expected to increase with the planned acquisition of Joint Strike Fighters, ongoing new F-16 purchases, and other upgrades to the Turkish Air Force fighter inventory. This increased demand will affect the current fighter training squadron curriculum and scheduling. This study focuses on issues related to 143rd Oncel squadron F-16 Pilot Training with this projected increase in number of student pilots (SPs). Completing the training periods on time is an important issue along with maintaining effective training performance. In our study, the Total Time of the training period serves as our primary performance measure. Simulation modeling concepts are applied to examine the training period based on the squadron syllabus. After constructing a simulation model using Arena, Design of Experiment, Regression Analysis and Metamodeling are implemented to capture the effects of the major factors, including SP, Instructor Pilot, Bandit and F-16, aircraft availability and how they interact with each other. The utilization of IPs and Bandits is also examined as a performance measure. In addition, a sensitivity analysis is conducted using the model with the current 143rd Oncel squadron resources.

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